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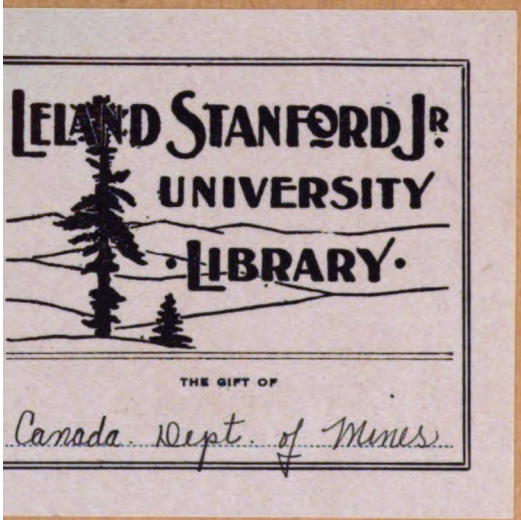

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CANADA

DEPARTMENT OF MINES

HON. CHARLES STEWART, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

GEOLOGICAL SURVEY

W. H. COLLINS, DIRECTOR

Summary Report, 1921, Part A

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SUMMARY REPORT, 1921, PART A

SILVER-LEAD DEPOSITS OF DAVIDSON MOUNTAINS, MAYO DISTRICT, YUKON

By W. E. Cockfield

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INTRODUCTION

The investigation of the Mayo silver-lead ores was, during the field season of 1921, confined to the mapping of three small areas in Davidson mountains, on which some prospecting had been done. These areas—Stand-to hill, Rambler hill, and mount Cameron—comprising a total of slightly more than 60 square miles, were mapped on a scale of $\frac{1}{12,000}$ and the maps (Nos. 1937, 1940, 1943) accompany this report.

The writer was ably assisted by N. T. Ellis, C. A. Merritt, and T. D. Guernsey, all of whom performed their duties in a satisfactory and efficient manner. Mr. Ellis was in charge of the topographical mapping, and Mr. Merritt and Mr. Guernsey assisted in both the topographical and geological work. The miners and prospectors of the district assisted in every way possible and for the many courtesies and favours received the writer wishes to express his hearty thanks.

GENERAL CHARACTER OF THE DISTRICT

Location and Accessibility. Mayo district takes its name from the town of Mayo, on Stewart river, 180 miles above its confluence with Yukon river.

Davidson mountains occupy the area enclosed by Ladue, McQuesten, and Beaver valleys, and form a range 30 miles long and 12 miles wide, having a general east-west trend. In general the southerly slopes of the range are gentle, being governed to some extent by the dip of the strata; the northerly slopes are steep, frequently precipitous. This also applies to those stream valleys flowing in an easterly or westerly direction within the range. Numerous sharp peaks occur, the highest of which is mount Cameron (6,893 feet).

The position of the areas with respect to Mayo is shown on Figure 1.

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During the summer a regular passenger and freight service is maintained on Stewart river by the steamers of the White Pass and Yukon route. From Mayo, roads lead to all the principal creeks. The most direct route to the properties under discussion is by way of Galena creek. A winter road leads from Galena creek to mount Cameron, and a trail leads from this winter road across Ladue lakes to Stand-to hill, and another, up Cache creek to Rambler hill. A better road for summer traffic leads to the base of Keno hill, where there is a trail down Christal creek to the Mount Cameron road.

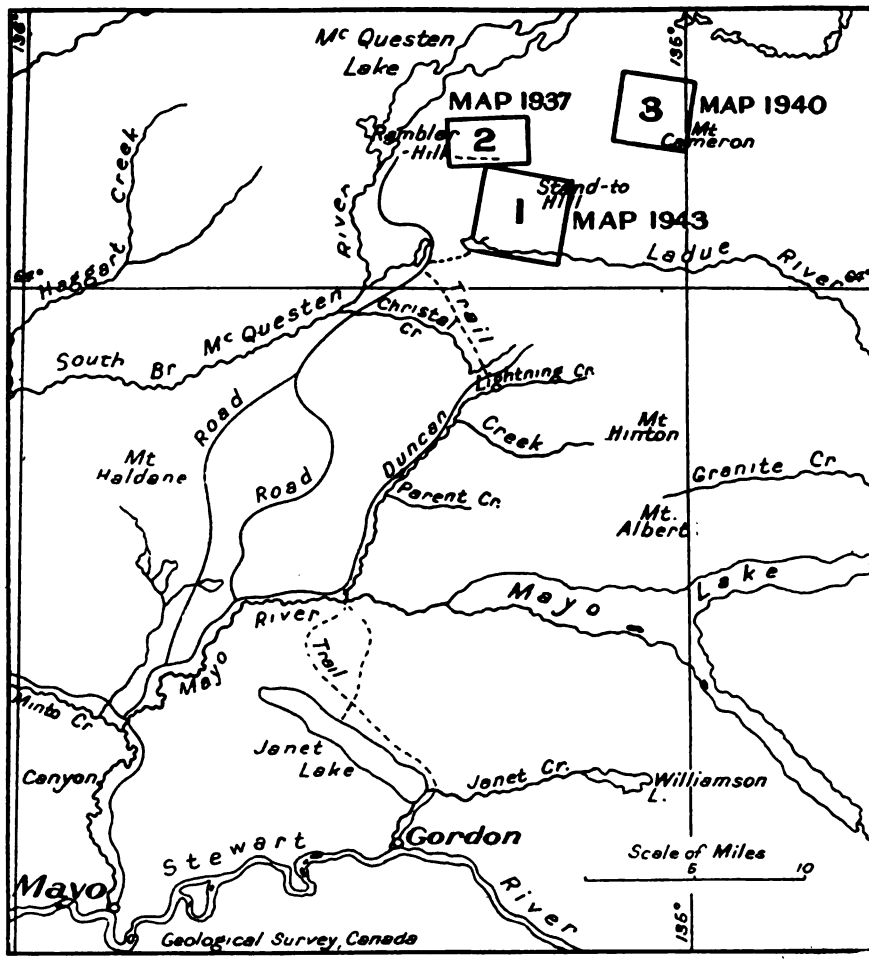

Figure 1. Index map showing location of mineralized areas, Mayo district, Yukon.
1. Stand-to Hill area.
2. Rambler Hill area.
3. Mount Cameron area.

The rates charged for freight vary greatly. From Dawson to Mayo the freight rate is from $50 to $60 a ton, depending on the stage of water in Stewart river. Ore at the present time is hauled 42 miles from Keno hill to Mayo for $30 a ton. The freight rate from Mayo to Keno hill is 15 cents a pound in summer and about half that amount in winter. In considering the three areas covered by this report it must be remembered that at present summer haulage is out of the question, there being no road, and that owing to greater distance and poorer roads winter haulage would be more expensive than to Keno hill.

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Topography. Mayo district lies within the physiographic province known as Yukon plateau, which is in this district characterized by its subdivision into isolated mountain groups, separated by broad, flat-bottomed valleys. The interstream areas are mostly flat-topped (Plate I A) and stand at an average elevation of 5,500 feet. These upland areas are parts of a former plain-like surface which has been uplifted and dissected. Occasional hills rise from the plateau to heights of 500 to 1,000 feet.

The district has been intensely glaciated, all but the upland having been covered by ice, which scoured the valley walls, giving to the valleys typical U-shaped cross-sections. The valleys are floored with glacial accumulations, through which the streams have formed terraces.

GENERAL GEOLOGY

Mayo area as a whole is floored by crystalline schists and gneisses. These are the oldest rocks of the district, and, by analogy with similar districts where the age of the rocks has been determined, they are tentatively referred to the Precambrian. These schists and gneisses consist of banded blue and white gneissoid quartzites, grading into quartz-mica schists, and mica schists, graphite schists, and crystalline limestone. These schists are intruded at many points throughout the district by later igneous rocks, diorite and diabase, granite, quartz porphyry, and granite porphyry.

These conditions also obtain in Davidson mountains—one of the three groups referred to above—where the greater part of the areas mapped consists of banded blue and white quartzites, quartz-mica schist, mica schist, graphite schist, and crystalline limestone. Cutting these are dykes and sills of greenstone, which vary widely in colour, texture, and composition, ranging from diorite to diabase, but which appear to belong to one general age of intrusion. These have been intruded along the bedding planes of the schists and have been subsequently sheared and altered. Many of them have become so altered, and now consist to such an extent of secondary minerals, that it is difficult to determine what their original compositions have been. In the field they are nearly always well-defined owing to their dark green colour, different texture, and the fairly sharp dividing line between them and the schists. Owing to their superior resistance they frequently control the topography and form the crests of the ridges.

The granitic intrusives are more prominent in Mayo district than in those parts of Davidson mountains that have been mapped; but one small body of granite was found in Stand-to Hill area, occurring well down on the slope toward Ladue valley. This occurrence is distinguished by the presence of muscovite, whereas in all other granitic occurrences observed in the district biotite is the predominating ferromagnesian mineral.

Overlying all the consolidated rock formations is a mantle of superficial deposits of varying thickness. It is thickest in the valleys, where boulder clay and stream deposits cover bedrock, but it is also prevalent on the hillsides and even on the upland surface where soil, frost-heaved blocks of bedrock, rock rubble, and talus make outcrops scarce. Outcrops are most numerous along the crests of ridges, particularly at the edges of the steep northerly slopes referred to above. They also occur in small jagged peaks at irregular intervals along the upland surface. On the hillsides rock outcrops are rare and are usually of the more resistant rocks, such as greenstone. In the valley bottoms there are occasional outcrops, particularly in the small canyons on the creeks. An attempt has been made to show on the map, by means of stippled areas, the distribution of the superficial deposits. It was found impracticable to show single outcrops and these, where fairly numerous, have, therefore, been grouped into areas.

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ECONOMIC GEOLOGY

The silver-lead ores of Davidson mountains are the only known deposits of economic value. They have many characteristics in common and are presumably similar in origin. They are veins formed by the filling of fault fissures. The ore mineral is galena in a gangue of siderite and quartz, with which is associated manganite, and in some cases pyrite, chalcopyrite, and zinc blende.

DESCRIPTION OF DEPOSITS

Stand-to Property. The Stand-to property (Map 1943) is situated on the east side of Homestead creek about 2 miles from its mouth. The workings are about 500 feet above the creek level. There is no road to the property, a winter trail from the workings across Ladue lakes to the Mount Cameron road—5 miles distant—being sufficient for its present needs.

The Stand-to property comprises seven claims, Elsie, Dorothy Brown, Janet Agnes, Two Donalds, Victoria, Mary Bell, and Glengarry, owned by J. Zahn, W. Forbes, D. Forks, D. MacDonald, J. Falconer, and J. A. MacDonald. These claims are grouped for the purpose of representation on the map. They were staked August 15 and 16, 1920. At the time of the writer's visit (July, 1921) the workings consisted of a number of surface trenches, and a 50-foot adit on the vein, about midway between the creek and the summit of Stand-to hill.

The vein is formed in a fault fissure which at the elevation of the workings brings a band of schist into juxtaposition with a greenstone sill, the fault having a vertical displacement of about 50 feet. The vein has been traced on the surface by open-cuts for 200 feet, but probably extends farther in both directions, for in this vicinity bedrock is covered by soil and talus, and the extent of the vein can be ascertained only by trenching. The average strike of the fissure is south 50 degrees east (magnetic); the dip is about vertical. The trend, however, is irregular, for the vein is broken by slip faults. The vein, which varies in width from 16 inches to 2 feet, is mineralized with galena, calcite, siderite, cerussite, limonite, manganite, chalcopyrite, and quartz. The galena occurs as bands from 1 to 6 inches wide in the other gangue minerals, and the chalcopyrite as small specks in the galena. The presence of the cerussite and limonite shows that some oxidation has taken place and possibly also some leaching. The workings are at no place more than 50 feet below the surface. Two samples were taken, No. 1 across 14 inches of the working face and No. 2 from the roof of the tunnel 25 feet from the entrance. These were assayed and the results are given below:

	No. 1	No. 2
Gold	Trace	Nil.
Silver	17·60 ozs. per ton	3·30 ozs. per ton
Lead	19·36%	4·40%

Many other claims have been staked around the original locations, but on the majority of these only representation work has been done. On one group, however, stripping and open-cutting have shown traces of mineralization. This group lies on the summit to the west of the head of Homestead creek, and consists of three claims, the Surprise, the Enterprise, and the Hillside, owned by C. Coutts and J. McKinnon. On the Hillside claim there are two veins, both of which show float containing iron, manganese, and lead minerals. On the Surprise claim a wide band of float with the same minerals apparently shows the location of another vein. Stripping work was in progress at the time of the writer's visit, but bedrock had not been reached, and consequently it was impossible to estimate the value of these veins.

The *Rambler Hill property* (Map 1937) is situated on Rambler hill, about 6 miles east of the foot of McQuesten lake. The workings lie above timber-line, at an elevation

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of about 5,000 feet. Eight claims are held, owned by Messrs. A. Martin, A. Lamb, A. R. Thompson, H. Colley, J. Alverson, G. Forey, J. Lake, and J. Robertson, each of whom owns an undivided eighth interest. The property is connected by a 4-mile trail to the winter road from Galena creek to mount Cameron. The workings consist of a shaft about 80 feet deep on the summit of the hill and a crosscut of 12 feet. The vein was traced down the hill for about 300 feet in elevation by means of open-cuts, and an adit has been started here.

At the time of the writer's visit (July, 1921) the shaft was full of water and the upper workings could not be examined. The data obtained from a previous examination[1] are given here for purposes of reference. The vein-filling consists of limonite, galena, pyrite, quartz, cerussite, anglesite (?), malachite, and chalcopyrite. Limonite makes up by far the greater mass of the deposit. Included in it are small nodules of galena, coated with oxidation products. Near the surface and extending downward for 37 feet are large masses of galena. Farther down, these disappear, leaving only the small nodules.

Galena appears in three open-cuts along the vein between the shaft and the adit. In the adit the vein is 3 to 4 feet wide. The strike and dip are both variable. The vein-filling consists of iron oxide and carbonate, manganite, and galena with lead carbonate and a little chalcopyrite. The galena occurs in small bands in the vein, and the chalcopyrite as small specks in the galena.

Two samples of the massive galena were taken. Although these do not represent the average content of the vein, they do give valuable information with regard to the ratio of ounces of silver to one per cent of lead. This ratio determines whether the ores can be concentrated sufficiently to pay for shipment. The samples gave the following results:

	No. 1	No. 2
Gold	Nil	Nil
Silver	36·80 ozs. per ton	36·00 ozs. per ton
Lead	54·91%	52·60%

On claims surrounding Rambler Hill property very little, other than representation work, has been done. In some places veins have been uncovered but work has not progressed far enough to enable much data to be given. One of the most promising of these properties is the Lucknow claim owned by A. R. Thompson. This lies on the long, flat stretch of upland to the east of Rambler hill. Here a fault fissure occurs: it can be traced on the surface by means of float for more than 2,000 feet and is partly exposed in a trench that has not yet reached bedrock but which discloses part of a broken outcrop of massive galena that is, probably, almost in place. Judging from the galena the vein has a width of 6 or 7 feet and of this width the massive galena occupies, probably, about 5 feet; but until more work is done nothing definite can be ascertained about the vein.

The Homestake group on Cache creek owned by A. Martin, W. J. Elliott, Fred Arnold, and B. Verschoyle, shows several veins. There are at least two fault fissures which have float showing iron manganese and lead minerals, but until the overburden is cleared away the character and content of the veins cannot be known.

At other points on the hill, particularly on both hillsides overlooking Rambler creek, galena float has been found, but the veins from which it comes have not been located. Some of this float is reported to be richer in silver than any of the galena tested during the past summer.

The *Mount Cameron property* (Map 1940) is situated on Cameron mountain about 45 miles in a direct line northeast of Mayo, and lies near timber-line on the central fork of Alverson gulch. The winter road from Galena creek to the property has not been completed, but there is a trail from the end of it to the workings. The distance from Mayo by way of this road is about 65 miles. The property consists of three claims, Cameron No. 1, No. 2, and No. 3 owned by J. Scougale, J. Alverson, and J. Philip.

[1] Cockfield, W. E., Geol. Surv., Can., Sum. Rept., 1918, p. 6 B.

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The workings consist mainly of an adit and a crosscut, but at the time of the writer's visit (August, 1921) the entrance to these was blocked by caving of the roof. There are, also, several trenches. The outcrop (Plate I B) is a decomposed mass of iron and copper minerals, chiefly limonite, manganite, malachite, and azurite, and judging from the material which had been excavated from the adit, the chief minerals present are pyrite, arsenopyrite, galena, sphalerite, chalcopyrite, limonite, siderite, manganite, and calcite. The galena, apparently, occurs in streaks and small masses in the other gangue minerals and, judging from the material on the dump, these streaks would reach a width of 6 to 8 inches. The mineralized outcrop is 50 feet wide and can be traced on the surface for 440 feet, and occasional patches of float show that the vein continues. When, however, the fault passes out of the limestone the fissure is, apparently, filled with a fault breccia composed of broken schist, apparently barren. Passing downward in the series the character of the fault is unknown, as its track is covered by forest growth.

A sample of the galena on the dump was picked so as to represent as nearly as possible the best of the material in sight. Although such a sample in no way represents the average content of the ore, it gives useful information as to the ratio of ounces of silver to one per cent lead. This assayed:

Gold	Nil
Silver	76·00 ozs. per ton
Lead	56·83%

It is manifestly impossible to make a fair estimate of the value of this property, as deductions made from the weathered outcrop are sure to be misleading. The vein is a large one—the widest noted in the Davidson Mountain group—and it extends probably for 2,000 feet, but the character and extent of any ore-bodies it contains cannot be judged from the few tons of material on the dump.

Conclusions

The ores of Stand-to hill, Rambler hill, and mount Cameron—and in fact of all the other prospects noted in Davidson mountains—are strikingly similar in mode of occurrence and mineralization. They also resemble the Keno Hill ores in many ways. Keno hill is 5 miles away directly across Ladue valley from Stand-to hill. There are, however, marked differences between the Davidson Mountain ores and those of Keno hill, the former being much lower in their silver content and mineralization. The Keno Hill ores almost invariably show a silver content of 3 or 4 ounces to 1 per cent lead, whereas the highest obtained during the past summer from the Davidson Mountain ores was 1·33 ounces to 1 per cent lead. This is due to the fact that the Keno Hill ores contain freibergite, a rich copper-silver salt, whereas in the others chalcopyrite, probably carrying little or no silver, is present. The cause of this difference in mineralization is not yet apparent.

In considering these properties from an economic standpoint it must be borne in mind that the deciding factor at the present time is the cost of transportation. Under present conditions it is doubtful if ore or concentrates could be successfully shipped unless the content realized at least $100 per ton. Ore cannot be hauled 65 miles by sled and then shipped several hundred miles to a smelter unless that ore is extremely rich—a condition which the deposits in the Davidson mountains do not fulfil.

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UPPER KITZAULT VALLEY, BRITISH COLUMBIA

By George Hanson

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INTRODUCTION

During the field season of 1921 a detailed investigation was made of the geology and mineral deposits of the Upper Kitzault Valley map-area. This area which lies at the headwaters of Kitzault river, 16 miles north of Alice Arm, B.C., is mineralized with quartz veins carrying values in silver. Two mines, the Dolly Varden and North Star, have shipped ore, the production from the Dolly Varden amounting to 1,304,411 ounces of silver. The area lies a few miles east of the eastern contact of the Coast Range batholith and is part of the great mineral belt that fringes this edge of the batholith. It was the writer's purpose to examine these mineral deposits, ascertain if possible their mode of origin and relation to the geological formations of the district, and to map these formations for the encouragement and direction of further prospecting in this and adjoining districts.

The district had not been examined previously by the Geological Survey, although in 1893 J. E. McEvoy mapped the shore geology of Alice Arm[1] and in 1911, R. G. McConnell[2] did some further geological mapping along Alice arm and reported upon the mineral deposits at the head of the arm. Kitzault district has also been described in the Annual Reports of the Minister of Mines, British Columbia, for 1913, and from 1915 to 1921.

The topographic map prepared in 1920 by W. H. Miller was used as a base for mapping the geology. R. W. Goranson and F. Buckle gave efficient assistance in the field. The writer wishes further to express his indebtedness to C. B. North and the officials of the Taylor Mining Company for their many courtesies and for the complete information placed at his disposal, also to D. W. Cameron, P. Anderson, the officials of the Consolidated Homestake Mining and Development Company, and to other holders of mineral claims for courtesies and helpful information.

GENERAL CHARACTER OF THE DISTRICT

Upper Kitzault Valley map-area embraces about 50 square miles and lies about 16 miles north of Alice arm. It is within the drainage basin of Kitzault river, which flows into Alice arm at the town of Alice Arm, a calling point for boats of the Union Steamship Company. The Grand Trunk Pacific Steamship Company maintains a

[1] Geol. Surv., Can., Ann. Rept., 1893, p. 13 A.
[2] Geol. Surv., Can., Mem. 32, 1913, pp. 81-94.

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regular service to Anyox, and there is a tri-weekly boat service between Anyox and Alice Arm. A narrow-gauge railway runs from the wharf at Alice Arm up Kitzault valley to Camp 8, a distance of 16 miles.

The district surrounding the map-area is characterized by the steep-sided valleys and rugged peaks typical of Coast Range topography. The relief in the district itself, however, is not great, the highest mountain being 5,450 feet above sea-level. All the mountain tops are rounded. The lowest point in the area is 850 feet above sea-level.

The steep sides of Alice arm are somewhat straight and show no projecting spurs. Alice arm has the appearance of a typical glacially eroded valley. The valley of Kitzault river, however, does not appear to have any features of glacial erosion except in its upper part. The same is true of its two largest tributaries, which head in glaciers. Boulder clay is found on the banks of Kitzault river as far as a mile south of the glacier, and above this point the valley is U-shaped. Evindsen and West Fork creeks also are U-shaped for a short distance below the present glaciers. It would seem that all the canyons in the district were cut by running water.

Continental glaciation has been effective up to elevations of over 5,400 feet above sea-level, as shown by glacial striæ and foreign boulders. Although there is this indisputable evidence for widespread glaciation, the valleys show features of glacial erosion only in their upper parts. Following continental glaciation, the Kitzault glacier was probably almost stagnant and, therefore, would not be an effective agent of erosion. It is possible that the first ice-sheet disappeared entirely and that there was a second and much more limited epoch of glaciation which filled only the higher valleys. The present glaciers are, apparently, remnants of the second period.

The chief streams are Kitzault river, and its tributaries Evindsen, West Fork, Clearwater, and Trout creeks. Clearwater and Trout creeks head in small lakes on the low divide, 2,700 feet above sea-level, between Kitzault and Nass rivers. The other streams mentioned head in glaciers. Practically all the streams in the area, except Kitzault river, flow in steep canyons in the lower parts of their courses. All the tributaries with the exception of Trout creek enter the Kitzault at a steep grade. Trout creek has the characteristic of a hanging valley in that it tumbles into Kitzault Valley bottom, in a series of falls and cascades 500 feet high.

Kitzault river heads in Kitzault glacier, flows in a steep but shallow canyon for 1½ miles, then continues in a broad valley as a shallow stream for about 3 miles. One-quarter of a mile north of the mouth of Evindsen creek it again enters a canyon, through which it flows for 3 miles. Below this it is a broad, shallow stream to Alice Arm, with the exception of a short canyon 7 miles from its mouth. The river follows very closely the strike of the surrounding rocks.

It is apparent that most of the minor details of topography in the map-area, such as canyons and low eminences, have resulted from the unequal resistance to erosion. From the combined topographic and geological map it will be seen that eminences, such as Combination mountain, Dolly Varden hill, and the low peaks to the southeast, are composed of rocks of the Dolly Varden formation. The rocks of this formation are harder and more resistant to erosion than the sediments of the Kitzault River formation. The same relation between eminences and character of rock is seen in the area between Trout lake and Kitzault river. The low pass to Nass river is underlain by soft rocks.

Where Kitzault river cuts through rocks of the Dolly Varden formation it flows in a canyon; where argillite forms the banks the river is shallow and broad. The softer rocks are cut away easily to form a broad valley, and to keep a uniform grade the stream cuts canyons in the more resistant rocks.

The climate is temperate. The summers are never very hot, and the temperature in winter does not fall much below zero. Precipitation is heavy throughout the year. July is usually a clear sunny month and September is occasionally fine. As a general rule June and August are showery. A winter's snow usually attains a depth of 15 feet in the valleys. Spring and summer are late. By the first of June snow still covers the rocks down to a line about 2,000 feet above sea-level.

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GENERAL GEOLOGY

GENERAL STATEMENT

The eastern contact of the Coast Range batholith lies a few miles west of the map-area, which is located in the great mineral belt that fringes the batholith. This eastern mineral belt has been investigated by the Geological Survey in many places[1]. That part of the belt lying between Unuk river on the northwest, and Skeena river on the southeast, a distance of 150 miles, has been examined at Unuk river, Bear river, Salmon river, Alice arm, Nass river, and Skeena river.

Alice arm lies midway between Unuk and Skeena rivers. In order to give the relation of the area to the whole region the geology along the belt will be briefly summarized.

The eastern contact of the Coast Range batholith trends northwesterly and the rocks bordering the intrusives on the east strike roughly parallel to the contact. On Unuk river the rocks are chiefly sedimentary. Along Bear river two sedimentary formations are found, one underlying and one overlying a thick series of volcanic fragmental rocks (Bear River formation). In Salmon River district a sedimentary series overlies the Bear River volcanics. Here there are also sills of quartz porphyry of late Jurassic age. In Kitzault River district a sedimentary series overlies volcanic rocks similar to the Bear River formation. The rocks along Nass river are chiefly sedimentary. This sedimentary series is apparently of the same age as the sediments overlying the volcanic rocks to the north. In Skeena River area, volcanic rocks occur similar in many ways to those farther north. Here again sedimentary rocks overlie the volcanic series.

It is believed that the volcanic rocks along this belt are, in the main, of Jurassic age. The overlying sedimentary rocks are probably of Jurassic age along the greater part of the belt. The sediments on Skeena river and also north to the Groundhog district are, however, of Lower Cretaceous age. It seems probable that the belt under discussion rose out of the sea at the end of the Jurassic period and that sedimentation continued along its eastern flank.

The geological formations in Upper Kitzault valley have been classified tentatively as follows:

Table of Formations

Period		Formation	Lithology
Quaternary.....	Pleistocene and Recent.....	.....	River gravels and glacial drift

[1]Wright, F. E., "The Unuk River Mining Region," Geol. Surv., Can., Sum. Rept., 1905, pp. 46-53.
Schofield, S. J., and Hanson, George, "Salmon River District", Geol. Surv., Can., Sum. Rept., 1920, pp. 6 A-12 A.
O'Neill, J. J., " Salmon River District," Geol. Surv., Can., Sum. Rept., 1919, pp. 7 B-12 B.
McConnell, R. G. "Portland Canal District", Geol. Surv., Can., Mem. 32, 1913.
McEvoy, J., Geol. Surv., Can., Ann. Rept., 1893, pp. 13 A-16 A.
McConnell, R. G., "Prince Rupert and Skeena River", Geol. Surv., Can., Guide Book No. 10, pp. 5-35, 1913.
MacKenzie, J. D., "Telkwa Valley and Vicinity," Geol. Surv., Can., Sum. Rept., 1915, pp. 62-69.
Also papers by W. W. Leach in the Summary Reports of 1906-1910, and G. S. Malloch in the Summary Report of 1911.

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Table of Formations—Continued

Unconformity

	Post-Jurassic(?)	.....	Lamprophyre and diabase dykes
	Intrusive contact		
	Jurassic	.....	Lamprophyre and diabase dykes
		Intrusive contact	
Mesozoic		Kitsault River formation	Argillites (fossiliferous), thickness 2,500 + feet
		Dolly Varden formation	Agglomerates and tuffs, thickness 3,000 + feet
		(Base unexposed)	

The formations have been given local names. When the areas intervening between Kitzault River district and other known areas are mapped, the names here proposed can probably be discarded in favour of other well-established names.

DESCRIPTIONS OF FORMATIONS

Dolly Varden Formation. The name is taken from the Dolly Varden mine which has been the outstanding mining property in the district. This formation underlies about one-half of the area of the district. The main body of the formation crosses the area in a northwest-southeast band 1½ miles wide. Another area outcrops south of Clearwater creek.

The formation consists chiefly of purple and green fragmental rocks probably over 3,000 feet in thickness. Tuffs and breccias predominate, but there are some andesite flows. The rocks of the formation are known locally as andesites.

The green members of the series contain fragments of porphyrite, tuff, feldspar, and quartz. The rocks are very much weathered. Calcite is the most abundant alteration product; sericite and chlorite are fairly plentiful, but epidote is rare. The purple rocks are of much the same mineral composition as the green members, but they appear to contain more magnetite. Vermilion red tuffs of the series contain a good deal of hematite in the matrix between the fragments of the tuff. A thin section of an augite andesite flow showed a content of andesine and augite with magnetite as an accessory mineral. Epidote and chlorite are the chief alteration products. Sericite and calcite are not common. A flow structure is evident in the arrangement of the feldspar laths.

The rocks are in general massive and their structural relations are not as a rule evident. In only a few places was it possible to determine the attitude of the beds. The rocks are very similar in composition and lack of structure to the Bear River formation of Portland Canal district, and also to the Kitsalas formation and parts of the Hazelton group along Skeena river.

A belt of rocks known locally as the copper belt enters the area mapped west of the Kitzault glacier and extends southeasterly to Evindsen creek. The belt is one-fourth to one-half a mile wide. It is bordered on the east by argillite of the Kitzault River formation and on the west by the Dolly Varden formation. Another similar belt of rocks enters the mapped area at the junction of Kitzault river and Homestead

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creek and extends northwesterly for a short distance north of Evindsen creek. This belt is bounded on the east by the Dolly Varden formation and on the west by argillites. The rocks of these belts contain a great deal of disseminated pyrite, and, consequently, the weathered outcrops are conspicuous and are easily distinguishable from a distance by their reddish-brown colour.

The rocks are severely sheared and weathered, and, consequently, are not easy to determine. Grey tuffs and breccias, apparently, predominate. Diorite appears to be present in the northern belt. Tuffaceous sediments and quartzite are also present. In many places the rocks contain a great deal of calcium carbonate and, particularly in the southern belt, frequently effervesce readily with cold dilute hydrochloric acid.

Lithologically the two belts are very much alike and probably belong to one horizon. The western border of the northern belt is gradational. The writer was unable to determine whether the copper belts were part of the Dolly Varden formation or a separate formation and thought best to include them with the Dolly Varden formation. McConnell in his traverse from Bear river to Meziaden lake, found that the Bear River formation where overlain by the Nass formation on the east, contained a rusty band one-half mile wide along the contact.[1] The area mentioned is about 15 miles north of the Kitzault area and the same belt may extend through the intervening unexplored area. Future work in adjacent areas may settle this problem.

Kitzault River Formation. A series of sedimentary rocks consisting chiefly of black argillites overlies the Dolly Varden formation to the north, northeast, and east, and occurs, also, in a band along Kitzault river. The thickness is estimated at over 2,500 feet. This series may yet prove to be the Nass formation, found 15 miles to the north, but for the present it is given the local name, Kitzault River formation. At the northwestern and southwestern corners of the mapped area, argillites, sandstones, and conglomerates are found. These rocks are coarser than the argillites to the east, but they appear to overlie the Dolly Varden formation. They have been mapped as part of the Kitzault River formation. To the south of the map-area these western sediments which have an easterly dip extend to Alice Arm and along the railway. The contacts of this southern part have not been studied.

Wherever the dips of the rocks of the Dolly Varden formation could be observed near the contact with the argillites the strike and dip of both formations are concordant. If the copper belt, however, is at a certain horizon in the Dolly Varden formation and not a result of hydrothermal alteration, it is very likely that locally at least, the Kitzault River formation lies unconformably on the volcanic series. In several places at the base of the Kitzault River formation tuffs and sediments are interbedded. This favours the view that the sedimentary period succeeded the volcanic period gradually, and that though there may be local unconformities, the argillites are in the main conformable on the series of extrusive rocks.

Stratigraphically above the interbedded tuffs and sediments and at the base of the argillite series is a fairly continuous band of greywacke and quartzite about 100 feet thick. The greywacke consists of poorly assorted, irregular grains of feldspar, quartz, biotite, and rock fragments. Calcite is the common alteration mineral. Above this band the rocks are almost entirely argillite. A few narrow bands of chert and slate pebble conglomerates, and narrow bands of sandstone are present. No limestone beds were found in the series, but some of the sediments are very calcareous. The argillites contain angular quartz and feldspar grains embedded in a black, fine-grained matrix. Much of the argillite is heavy bedded, but in some places, thin bands of black argillite alternate with thin beds of argillaceous sandstone.

Fossils from the sandstone members of the transition zone of interbedded tuffs and sediments at the base of the Kitzault River formation were identified by F. H. McLearn as *Gryphæa* sp., *Oxytoma* sp., *Belemnites* sp., and *Rhynchonella* sp. Mr. McLearn writes: "It is regrettable that in the present stage of study of the Mesozoic

[1]McConnell, R. G., Geol. Surv., Can., Mem. 32, 1913, pp. 75-76.

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of British Columbia a more exact report cannot be given. It can be said, however, that the above fauna is certainly either Jurassic or Cretaceous and very probably Jurassic."

Lamprophyre Dykes. Intrusive into the rocks previously mentioned are numerous lamprophyre dykes. The rock is black and resembles diabase, but very few typical diabase dykes are present. Thin sections from some of the dykes contain albite-oligoclase feldspar laths, a little orthoclase, rare quartz, and numerous long, well-formed crystals of light brown hornblende. Others contain oligoclase-andesine feldspar laths and augite. Apatite, present as long slender needles, is a common accessory mineral in all these dykes. Chlorite and calcite are the usual alteration products. Some of the dykes are cut by mineral veins; others cut mineral veins, but are cut by faults. Others are later than both the veins and faults.

Some of the dykes, therefore, are apparently of Jurassic age and some are post-Jurassic.

Pleistocene and Recent. Glacial drift is not plentiful. Boulder clay on the banks of Kitzault river is 50 feet thick for a mile below the glacier, and is also found on the hillside east of Camp 8.

Stratified sands and clays occur south of the map-area about 9 miles north of Alice Arm and about 400 feet above sea-level. Similar deposits have been found at this level in several inlets along the coast. Marine fossil shells were found in similar clays along Bear river[1].

STRUCTURE

In Kitzault River district, as elsewhere along the borders of the Coast batholith, the rocks strike roughly parallel to the contact of the intrusive mass. In this area the strike is approximately north 25 degrees west. Structures showing the attitude of the beds of the Dolly Varden formation are scarce. On Combination mountain, between Evindsen creek and the West Fork of Kitzault river, the breccias dip to the west, and here the argillites and the volcanics appear to be conformable. Similar relations exist at the eastern contact of the small area of tuff extending southeast from Kitzault glacier.

The area of argillite outcropping along Kitzault river between Evindsen creek and Kitzault glacier is a canoe-shaped syncline. This area joins with the north-east dipping sediments north of Clearwater creek and also with the large area of sedimentary rocks east of Kitzault valley. The sediments along the western part of the sheet dip to the west. These areas were probably originally continuous.

It is believed that an anticline crosses Combination mountain. A syncline exists along Kitzault valley, and part of the sediments are still preserved here. This is succeeded by another anticline between Trout lake and Kitzault river. Folding, transverse to the main structural lines, caused the formation of a transverse anticline at the mouth of Evindsen creek. This is succeeded by a transverse syncline about a mile farther north.

Judging from the number of faults encountered in mine workings, the district has been subjected to a great deal of faulting. The greatest horizontal offset noted was 160 feet. The throw may have been much greater than this. Most of the faults have a north-south trend and most of these are reverse faults. Several faults with an east-west trend were observed. The only place where faulting could be studied was underground; consequently, the data obtained were not complete enough for the working out of the nature of the regional movements which produced the faults.

ECONOMIC GEOLOGY

DISCOVERY

Before the advent of the railway, the upper parts of Kitzault valley were difficult of access. The canyons and steep slopes could not be travelled. For this reason, although many mineral claims were located around Alice arm in 1901, it was not

[1] McConnell, R.G., op. cit., p. 22.

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until 1911 that any mineral claim was located on the upper waters of Kitzault river (Figure 2). The first claim recorded was the Dolly Varden, staked by Evindsen, Pearson, and partners. The other claims staked were located in the copper belt. Not until after 1913 was attention directed to the properties located in the breccias and tuffs.

The properties in the district were described in the Report of the Minister of Mines, B.C. in 1913. Since 1915 descriptions of the district have been given each year.

Production

1919	42 tons	Yielding	50,562	ozs.	silver	Dolly Varden
	6,668 "	"	376,562	"		"
	27 "	"	968	"		North Star
1920	93 "	"	82,298	"		Dolly Varden
	27,944 "	"	749,340	"		"
1921	1,862 "	"	45,647	"		"

Also a small shipment from the North Star.

GENERAL STATEMENT

The primary veins and replacements in the district were formed during the closing stages of igneous activity of the Coast batholith. The metals and much of the accompanying vein matter were derived probably from ascending, or hypogene, solutions. The primary vein matter now exposed at the surface was formed, apparently, several thousand feet below the surface. Since then erosion has stripped off rock several thousand feet in thickness. The rock was weathered and disintegrated more rapidly than it was removed. The metals from the outcropping veins were, consequently, dissolved and the solutions seeped downward along the easiest passageways. Solution, chemical reaction, and replacement went on, resulting in secondary minerals being deposited by these surface, or supergene, solutions. The process continued until Pleistocene time, and in several places deposits of secondary silver ore were formed. Pleistocene erosion stripped off all the oxidized part of the veins and probably part of the enriched portion, leaving the veins practically as they are today. It is possible that nuggets of silver removed by Pleistocene erosion still remain in Kitzault river.

The mineral deposits have been classified as follows:[1]

Quartz veins and replacements in the volcanic fragmental rocks.
Quartz veins and replacements in the copper belt.
Quartz veins in the sedimentary rocks.

Upper Kitzault valley is only a small part of the area examined by Mr. Turnbull, but the classification is suitable.

Not all the claims in the district were examined. A brief description follows of those properties visited, and other descriptions can be found in the British Columbia reports for 1913, and 1915-1921.

QUARTZ VEINS AND REPLACEMENTS IN VOLCANIC FRAGMENTAL ROCKS

All these properties—which are noted for their content in silver—are located in the Dolly Varden formation, exclusive of the copper belt, and all of these lie either in the green or grey members of the formation, or at the contact between these rocks and purple breccias. The veins contain a moderate proportion of metallic minerals and where the values are high in silver the mineralization is usually native silver, ruby silver, argentite, etc. High values from a galena or grey copper ore are not so common.

In some of these properties barite and jasper are common gangue minerals. The richer silver veins have, however, a quartzose gangue. It is probable that the barite

[1] Turnbull, J. M., "Alice Arm District", Ann. Rept. Minister of Mines, B.C., pp. K 53-K 88, 1916.

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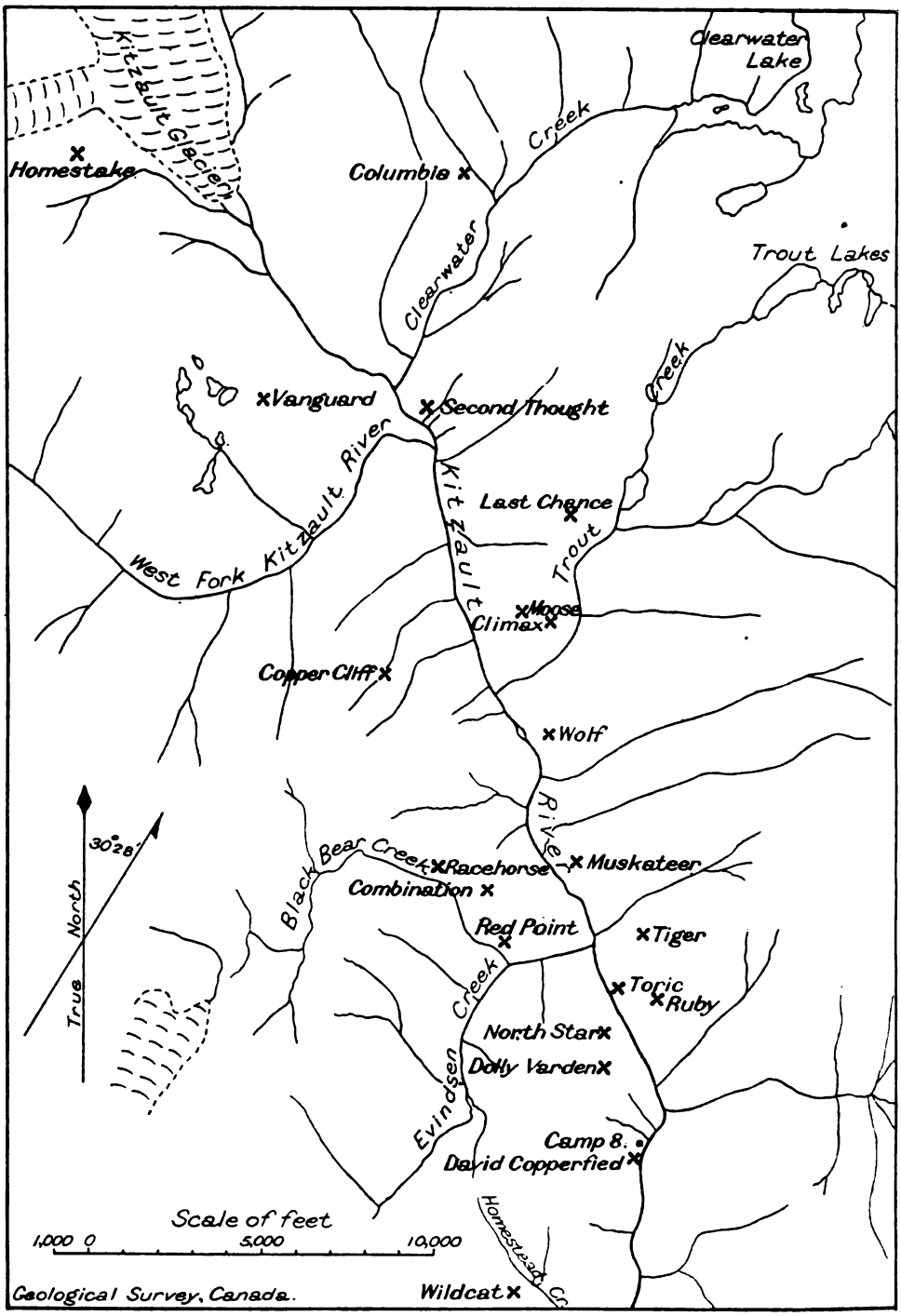

Figure 2. Diagram showing location of mining properties in Upper Kitzault valley, B.C.

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was formed during the period of primary mineralization, and that it did not contain metallic minerals. Secondary ore is formed chiefly by the replacement of primary ore; consequently, even after secondary enrichment, the barite would not contain much ore. Further, quartzose vein matter, being brittle, might fracture more readily than barite, and surface solutions would then penetrate the quartzose gangue more easily.

North Star-Toric-Ruby Mineral Zone

This zone appears to be continuous northward from the Dolly Varden through the North Star to the Toric, where it bends sharply (at Kitzault river) and extends southeastward through the Toric and Ruby groups, beyond which it has not been traced. This zone lies in grey breccia and has a hanging-wall of purple breccia. It is of indefinite width, up to perhaps 150 feet in some places. It is not mineralized throughout its entire width, but is simply a zone in which quartz barite veins lie roughly parallel to the contact with the overlying purple breccia. The rocks along the zone appear to be folded into a northerly plunging anticline. The Toric is located at the apex, the Ruby on the eastern limb, and the North Star on the western limb of the anticline. The veins are in general bedded veins; that is, they are parallel to the strike and dip of the enclosing rocks.

This zone may pinch out in Dolly Varden ground or it may be the eastern extension of the Dolly Varden zone faulted into its present position, or interrupted by a northerly-plunging syncline. No evidence was found to show that the zone was faulted here and it probably continues for some distance past the Ruby group to the southeast. The vein in the Tiger group may belong to this zone, as a syncline passing between the Ruby and the Tiger group could bring this about. Further field work is necessary, however, to settle these problems.

The *North Star group* is controlled by the Alice Arm Silver Mining Co., Ltd. Development consists of open-cuts and 250 feet of tunnel. The North Star vein has a north-south strike and dips steeply to the west. The country rock is grey breccia, although purple breccias are present 50 feet west of the vein. Lamprophyre dykes parallel the vein and in some places form its foot or hanging-wall. Faulting has taken place, but development has not been extensive enough to ascertain whether the parts of the vein observed are one vein faulted, or two veins. The vein is 4 to 12 feet wide and has been traced for over 500 feet.

Silver is the metal extracted. Where mining has been carried on the vein is essentially a quartz-pyrite vein carrying the silver minerals ruby silver, native silver, and argentite. Lower down the hill toward the Toric, the vein changes in character and becomes essentially a barite vein containing a little galena and small amounts of silver.

The *Toric group* is owned by Strombeck Bros. Development consists of a number of open-cuts and 90 feet of tunnel. Two or more veins are exposed striking southeast and dipping to the northeast. The main vein is 4 to 12 feet wide and has been traced for over 500 feet. At Kitzault river the vein consists almost entirely of barite. Around the tunnels and more promising stripping is a jasper-barite quartz vein. The jasper-barite vein matter is beautifully banded, forming irregular crustification patterns. Parts of the vein contain numerous irregular fragments of rock cemented by jasper and barite. In several places thin bands of barite and jasper alternate with thin seams of galena. Metallic minerals are not prominent in the barite-jasper gangue, but some of this vein matter carries about 20 ounces of silver per ton. During the summer of 1921 a new ore-shoot was uncovered within the main vein. This shoot contains native silver, ruby silver, galena, etc., in a gangue of quartz. The values are high.

The *Ruby group* is owned by T. W. Shackelton. Development consists of a few open-cuts and 110 feet of tunnel. The foot-wall is a greenish, and the hanging-wall a purple breccia. The vein matter consists almost entirely of quartz. Pyrite is

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present but other minerals are rare. The vein is 4 to 8 feet wide and is parallel to the strike and also apparently to the dip of the enclosing rocks. Open-cuts extend for an horizontal distance of 350 feet and appear to be on the same vein.

Dolly Varden Mineral Zone

This is a zone of grey breccia underlying a series of purple fragmental rocks. Quartz veins in the zone are, in general, parallel to the strike of the rocks. The Dolly Varden vein is one of these veins. Its western extension has not been traced beyond the Dolly Varden claims, but the zone in which it is located appears to continue west to Evindsen creek through either the Silver Tip or Royal groups or through both. The eastern part of the vein is cut off by a fault, which offsets the vein east of this in a southern direction.

The *Dolly Varden group* is owned by the Taylor Mining Co. Development consists of open-cuts, 7,000 feet of tunnels, raises, etc., and a good deal of diamond drilling. The main vein strikes roughly east and west and dips 60 degrees to the north (Figure 3). It lies in part along the contact between a purple and green breccia and in part in the latter rock. The primary vein matter was deposited from ascending solutions. The process of vein formation was accompanied by a considerable development of pyrite, and some quartz and sericite, in the foot-wall. The purple breccia hanging-wall has not been altered by solutions accompanying ore deposition.

Numerous reverse faults with a north-south strike and a steep westerly dip offset the vein. Later normal faults with approximately the same strike and dip also cut the vein; consequently the vein outcrops as a series of disjointed blocks 30 to 200 feet in length. The greatest horizontal offset along faults in the mine workings is 160 feet. Horizontal faults are also present. Lamprophyre dykes cut the vein, some of which antedate and some postdate the faults. Mining is rather a complicated proceeding.

The vein has been traced for 1,500 feet, but the eastern 300 feet has not been developed underground. Mining has been carried on in the four fault blocks adjoining this, an horizontal distance of 300 feet. The western extension of 900 feet has not been developed underground except at the western end where some diamond drilling was done. This vein varies from 8 to over 20 feet in width.

About 100 feet north of the western extension another quartz vein is exposed, but has not been investigated. Another large body of quartz and brecciated rock cemented with quartz extends into the Dolly Varden ground from the North Star claims. This body has been tested in two places by diamond drilling.

The main vein is essentially a silver-bearing quartz-pyrite vein. Pyrite is fairly abundant. Zinc blende, galena, chalcopyrite, and tetrahedrite, are rare. The ore extracted contained a good deal of native silver, ruby silver, and argentite. Quartz is the predominant gangue mineral, but calcite, barite, and jasper are present in small amounts. Barite is plentiful in some parts of the vein, but was not common in the ore extracted.

In the upper workings, native silver, ruby silver, and argentite were plentiful and occurred in plates and seams as much as a quarter of an inch in thickness, and in numerous irregular masses. In the deeper workings, the native silver occurred in thin flakes and wires, and the other silver minerals as well were found chiefly in minute fractures. It is believed that the ore mined was essentially secondary, i.e. it was the result of enrichment of primary vein matter by descending surface solutions. The thick plates of silver, etc., near the surface, represent intensive enrichment. The thin flakes and wires of silver are near the bottom of the enriched zone where secondary action was dying out.

Ore has been worked to a depth of 240 feet; 36,609 tons yielding 1,304,411 ounces of silver have been shipped since 1919. One shipment of 42 tons in 1919 yielded

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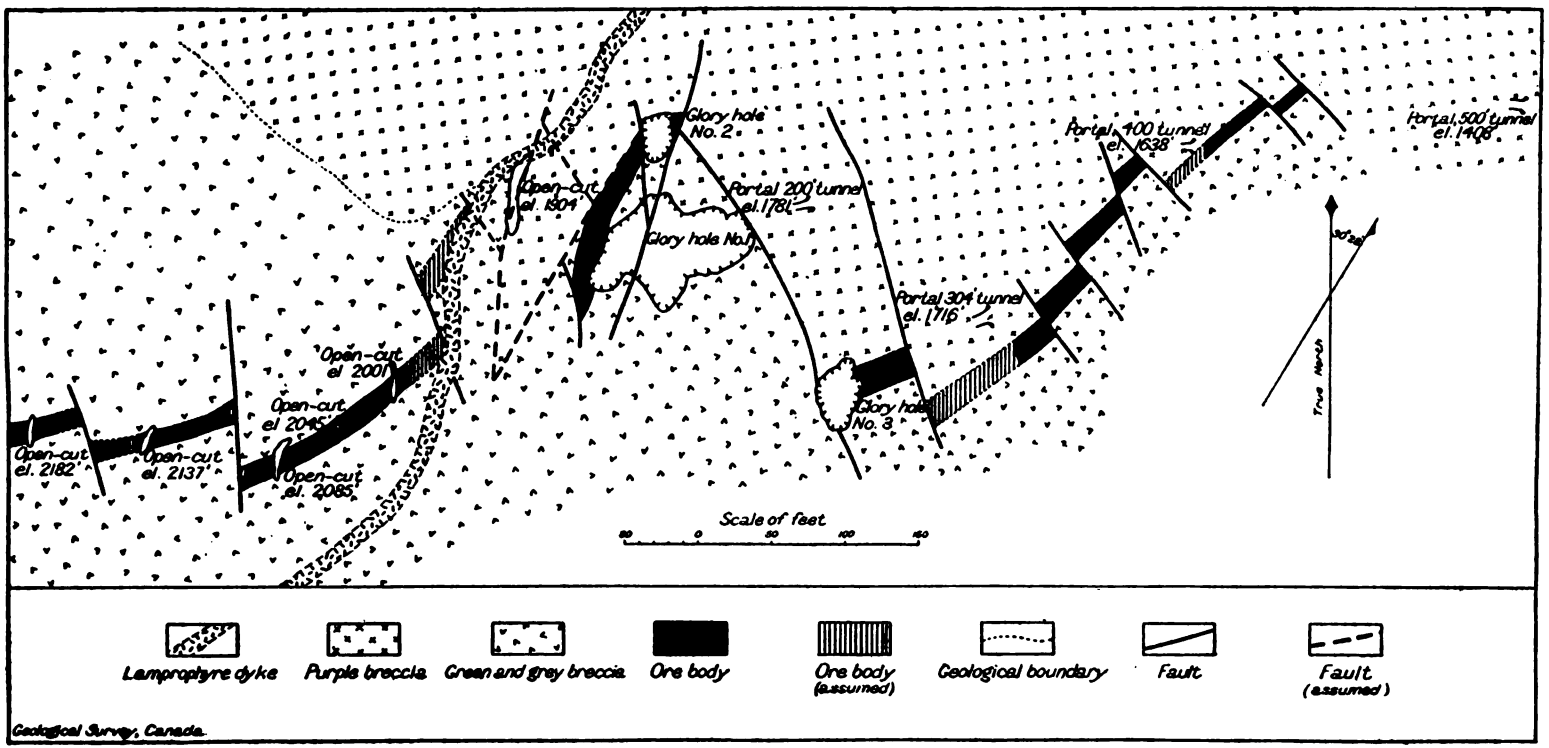

Figure 3. Plan showing geology and surface workings of the Dolly Varden property, Upper Kitzault valley, B.C.

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1,202 ounces of silver per ton. The lowest grade ore shipped yielded 24 ounces silver per ton.[1]

Other Properties

The *Tiger group* is owned by Ed. Pickett. Development consists of a number of open-cuts, 185 feet of tunnel, and about 1,500 feet of diamond drilling. The country rock is a hard, grey, fine-grained tuff. The vein is 4 feet to 18 feet wide striking north 30 degrees east and dipping steeply to the northwest. It has been traced on the surface for several hundred feet. The vein has been faulted into four or more blocks by faults having an east-west trend. Mineralization consists of pyrite, and a little galena and zinc blende, in a gangue of quartz. Ruby silver and native silver occur locally in small quantities. Assays of samples across 18 feet of vein matter have run as high as 38 ounces of silver per ton, but in most places where samples have been taken across the vein the values have been lower. Apparently much of the vein is low grade, although in places high grade material has been obtained.

The *Wolf group* is owned by the Taylor Mining Company. Development consists of a large number of open-cuts, a tunnel 85 feet long, and several thousand feet of diamond drilling. The country rock is a grey breccia. The property was only hastily examined; it contains, probably, only two veins, but faulting has so dislocated them that they appear to be three. They vary in width from 10 to 50 feet and are the largest known in the district, being 1,500 feet long, as proved by open-cuts. The metallic minerals are chiefly pyrite, and some galena, ruby silver, and native silver. Development has not shown very high values in silver, but it has indicated a large body of possible ore of moderate to low grade. One vein strikes north 70 degrees east and apparently dips to the northwest; the other strikes north 20 degrees east and has a westerly dip.

The *Musketeer group* is owned by A. D. Meenach. Development consists of a few open-cuts and 185 feet of tunnel.

The country rock is a hard, fine-grained tuff and appears to contain some sedimentary material. The tunnel is in part a drift along the southwestern side of a vein striking south 50 degrees east. A crosscut penetrates about 50 feet of mineralized rock. Although a good deal of work has been done the size and attitude of the vein or veins are not clear. The mineralization is much like that of the Toric vein, in that it contains a good deal of jasper and barite as well as quartz. The metallic minerals are pyrite, chalcopyrite, galena, and zinc blende. Fair values in silver have been shown in assays.

The *Moose group* is owned by D. W. Cameron, M. Donald, and associates. Development consists of a number of open-cuts and over 300 feet of tunnel. The country rock is a medium to fine-grained grey tuff. The vein varies in width from 4 to 18 feet. It strikes due east, dips steeply to the north (Figure 4) and has been traced for 450 feet. Development has shown that the vein has been broken by two sets of faults, one with a north-south strike, and one with an east-west strike. The lower tunnel has developed the ore-body 200 feet below the outcrop. The metallic minerals are essentially pyrite, tetrahedrite, and galena in quartz. It is probable that silver minerals are present. Picked samples from the surface have assayed over 200 ounces silver to the ton. The vein has not been sampled very extensively underground, but at one crosscut 150 feet below the surface, 5½ feet along the hanging-wall assayed over 17 ounces silver per ton.

The *David Copperfield group* is owned by W. McLean. Development consists of a number of open-cuts and a short tunnel. The country rock at the eastern side of the property is a green tuffaceous sediment. On the western side of the rocks are

[1]For further details of the Dolly Varden mine the reader is referred to the Reports of the Minister of Mines of British Columbia, 1915-1921, and especially for evidence for secondary enrichment to a paper by the writer on the Dolly Varden mine, which was presented at the Annual Meeting of the British Columbia Division of the Canadian Institute of Mining and Metallurgy in Vancouver in February, 1922, and which will appear in an early number of the Bulletin of the C.I.M.M.

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tuffs and breccias. The vein varies from a few feet to 12 feet in width and is composed of quartz, barite, calcite, galena, zinc blende, and pyrite. Low values in silver have been obtained. Metallic minerals are not plentiful. From the eastern boundary of the group the vein extends northwesterly for perhaps a thousand feet. On the east it passes into the Surprise claims which adjoin the David Copperfield. Here the vein is split up into a number of quartz-barite veins separated by tuffaceous sedimentary rocks.

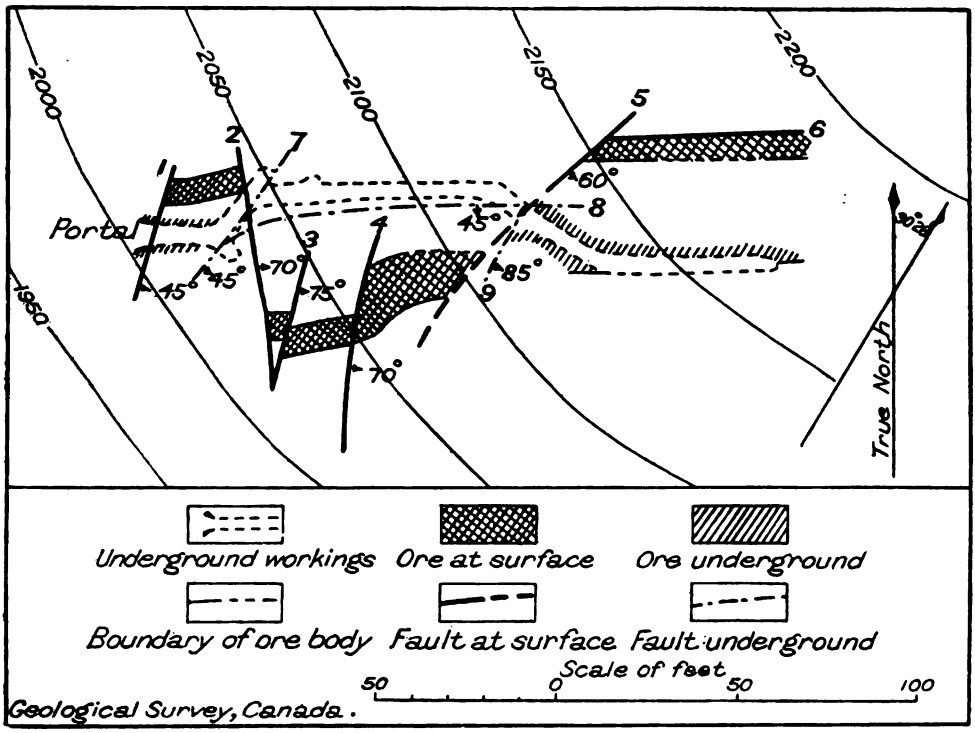

Figure 4. Plan showing ore deposit and lower tunnel, Moose property, Upper Kitsault valley, B.C.

The *Last Chance group* is owned by A. McPhail and P. Morley. Development consists of open-cuts, a tunnel, and diamond drilling. The vein is in the volcanic rocks near the contact with the sedimentary rocks. The owners believe that the lead has a strike of about north 80 degrees west, and state that it has been traced for 600 feet. In several places the lead is evidently a crushed and brecciated zone cemented by vein matter and in some places is 15 feet or more wide. The metallic minerals are chiefly pyrite, galena, and tetrahedrite. The gangue minerals are quartz, barite, jasper, and calcite. High assay values have been obtained from picked specimens.

Good mineral specimens were seen from the Climax, Mr. Hauber's claims, and other claims in the district, but, since the writer's examination of these properties was very brief, they will not be described here.

QUARTZ VEINS AND REPLACEMENTS IN THE COPPER BELT

Properties of this type are quartz veins and carry low values in silver, but in some places good values in copper. Most of the veins or lodes in the copper belt have apparently been formed along brecciated zones and shear zones. Low values in

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gold are reported, and in some of the properties the mineralized zones are simply bands of country rock carrying disseminated pyrite and chalcopyrite. Irregular gashes and small lenses of chalcopyrite are found in a few places.

The *Homestake group*, owned by A. Davidson and partners, is now being developed under option by the Consolidated Homestake Mining and Development Co., Ltd. Development consists of a number of open-cuts and tunnels. The country rock is apparently a fine-grained breccia of the copper belt. The property contains several quartz veins, of which the two largest have apparently been traced over several claims. The width of the veins in some places exceeds 50 feet. This width is not entirely vein matter but consists of a few closely spaced veins. In some places the vein matter is over a width of 20 feet. The strike of the veins is roughly northwest. The veins or lodes appear to represent mineralization along brecciated zones and shear zones. Operations on a large scale might be carried on here if the values are high enough. The mineralization consists chiefly of pyrite, chalcopyrite, galena, and zinc blende, in a gangue of quartz.

The *Vanguard group* is owned by Morris Peterson and Strombeck Brothers. Development consists of open-cuts and 170 feet of tunnel. The country rock is a grey breccia of the copper belt. Mineralization here appears to be in lenses or lenticular veins. In one place about 6 feet and in another place 3 feet of almost pure chalcopyrite is exposed. The strike of the ore-shoots was not clear to the writer from his brief examination. The tunnels, driven under the best exposures, show disappointing results. There may be a number of small, high-grade lenses, however, and faults are likely to be present. Careful work in outlining the ore-bodies on the surface might well repay the owners. The most important mineral is chalcopyrite. Pyrite is fairly common and a little galena is present. The ore also contains values in silver and gold.

The *Copper Cliff group* is owned by A. Davidson and partners. Development consists of open-cuts, 50 feet of tunnel, and some diamond drilling. The country rock is grey in places resembling a diorite and in others a tuffaceous sandstone. The workings are near the contact with the slates on the east. The grey country rock contains a good deal of disseminated pyrite and some chalcopyrite. At the time of the writer's visit snow filled most of the cuts, but it was evident that the ore here was of a disseminated type. The mineralized zone is several hundred feet wide.

The *Racehorse and Combination groups* are owned by Chas. Swanson and partner. Development in the former consists of open-cuts and 72 feet of tunnel, and in the latter, of open-cuts and 135 feet of tunnel. The workings of these two groups lie along the same mineral zone and appear to be on the same vein. The country rock is a grey breccia and coarse tuffaceous sandstone of the copper belt. The cuts are located on a quartz vein striking about north 65 degrees west. The vein averages about 10 feet wide, but in some places is wider. The tunnel on the Combination group crosscuts over 20 feet of vein matter. In places the vein is solid quartz, but in a few places it appears to be an imperfect replacement along a brecciated zone. Small masses of chalcopyrite are found locally, but the whole seems to be very low grade. The metallic minerals are pyrite and chalcopyrite. The vein has been traced for 3,000 feet in a northwesterly direction from the Combination tunnel.

The *Redpoint and Wildcat groups* are owned by Evindsen and partners, and by A. Davidson and partners. On the Redpoint a broad zone contains disseminated pyrite, chalcopyrite, pyrrhotite, and also some quartz veins. The mineralization on the Wildcat is pyrite, chalcopyrite, galena, and zinc blende, chiefly as disseminations and irregular gash veins.

QUARTZ VEINS IN THE SEDIMENTARY ROCKS

In Upper Kitzault valley these veins contain low values in gold and silver, but the veins of this type have not been developed to any great extent. They are in general either stringer leads or lenticular veins lying parallel to the strike and dip of

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the enclosing sediments. Persistent veins crosscutting the strike of the sediments are less common. A common feature of the veins is the presence of numerous fragments of argillite enclosed in the quartz.

The *Second Thought group* is owned by Geo. Casey and J. Graham. Development consists of open-cuts and 35 feet of tunnel. The mineralization is in quartz veins lying parallel to the dip and strike of the country rock, which is a black argillite. Two veins, 4 to 6 feet wide, are known. In most places these veins are split up into a number of closely spaced veinlets. The vein matter is white vitreous quartz containing numerous inclusions of argillite. Metallic minerals are scarce, but it is claimed that some samples have yielded high values in silver and gold. Values are evidently very sporadic. It is interesting to note that the Esperanza mine at Alice Arm which has been worked on a small scale for a number of years, obtains its ore from a quartz vein in an argillite country rock.

The *Columbia group* is owned by P. Anderson. Development consists of a number of open-cuts and about 100 feet of tunnel. The country rock is argillite striking east-west and dipping north. Two veins are exposed on the property. The larger one is 10 to 15 feet wide of fairly solid white quartz, and is very uniform and persistent. The veins strike north-south cutting the argillites at right angles to their strike. Metallic minerals are scarce. Assay values up to $6 in gold have been obtained.

Several properties in the argillites were not visited.

PROSPECTING

The following remarks apply to upper Kitzault valley.

The volcanic fragmental rocks of the Dolly Varden formation are worth prospecting for silver-bearing veins. The purple and red members of this formation do not appear to contain any silver veins, the grey or green members containing all the known silver veins in the district.

Secondary enrichment has not proceeded at a uniform rate throughout any area, nor even in any particular vein. Consequently, if a vein is stripped in a few isolated places and found to be too low grade for mining in these places, it does not follow that the intervening parts of the vein are also of low grade, and vice versa. In prospecting the silver-bearing veins in the district, thorough surface examination is of the greatest value.

Surface prospecting would probably be of value along the Dolly Varden mineral zone, the North Star, Toric, Ruby mineral zone, and the extension of the Ruby zone.

If the values are contained in a native silver, ruby silver ore, it is probable the silver content will decrease in depth. Where the silver is contained in a grey copper, galena ore, the values will probably be more persistent in depth.

Where surface ores contain thick plates and leaves of silver and similar seams of ruby silver, and where fracturing has been extensive, high values can be expected to continue to greater depth than where surface ores contain very thin flakes of native silver, etc.

It is worthy of note that the high-grade silver values are obtained from a siliceous ore. In barite veins, the higher grade vein matter is found in quartzose shoots.

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COAST AND ISLANDS OF BRITISH COLUMBIA BETWEEN BURKE AND DOUGLAS CHANNELS

By V. Dolmage

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INTRODUCTION

The field season of 1921 was spent in making a shore-line geological map of the coast and islands of British Columbia lying between Burke channel and Kitimat, and examining the mineral deposits of this district. This work is a continuation of that begun by O. E. LeRoy[1] in 1906, continued by J. Austen Bancroft[2] in 1907, and by R. P. D. Graham[3] in 1908 who completed the shore-line mapping as far as Bella Coola, at the head of Burke channel. Three months of 1921 were spent in the field, two weeks of which were devoted to the study of Surf Inlet gold mine, which is one of the large producers of the province. Admiralty charts on a scale of approximately 4 miles to the inch served as a base for geological mapping, and the work was confined chiefly to the shore-line.

Almost no previous geological work has been done in the region. The only published information on the country is in brief descriptions in the recent numbers of the Annual Reports of the Minister of Mines of British Columbia of the mineral deposits of the country, and a short description of the whole coast region by R. G. McConnell.[4]

M. E. Hurst and D. H. Rae assisted in the work, the former taking charge of the shore-line mapping while the writer was at Surf inlet. Much assistance was also received from the miners and prospectors of the district, and the writer is particularly grateful to Mr. F. H. Penn, superintendent, and Mr. P. W. Racey, mining engineer, at Surf Inlet mine, for their friendly co-operation and assistance. The writer is also indebted to Mr. J. Koski for information as to the hot springs of the district.

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[1] Geol. Surv., Can., Pub. No. 996, 1908.
[2] Geol. Surv., Can., Mem. 23, 1913.
[3] Geol. Surv., Can., Sum. Rept., 1908, pp. 38.
[4] Twelfth Inter. Geol. Cong., Guide Book No. 10, 1913

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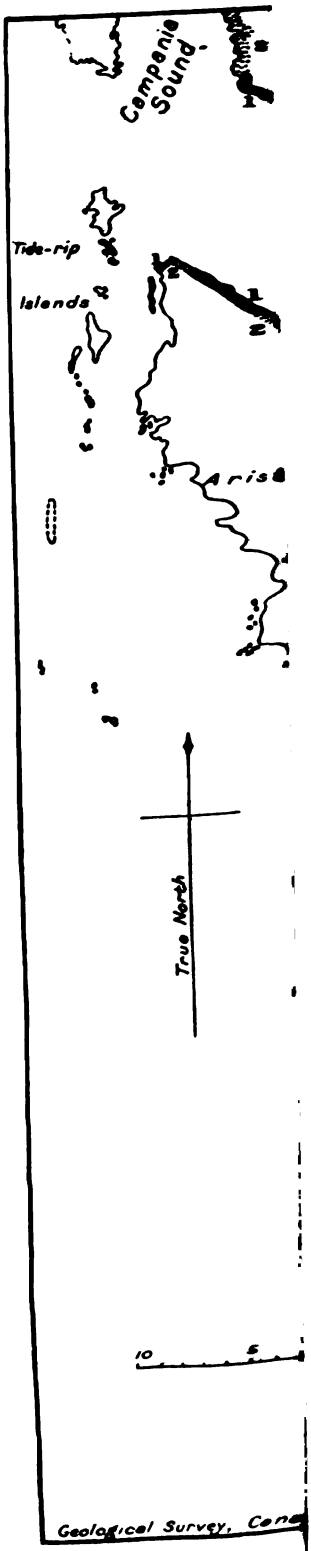

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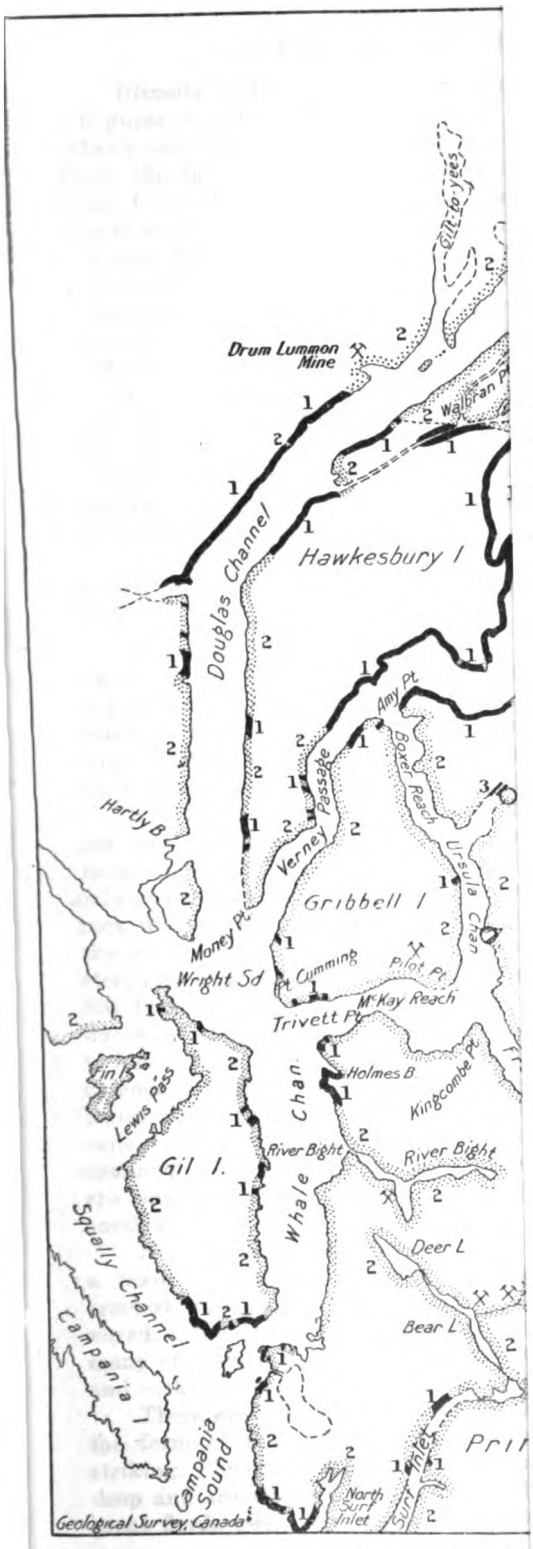

Figure 6. Coast and isl

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GENERAL CHARACTER OF THE DISTRICT

Climate and Population. The section of the coast dealt with in this report (Figures 5 and 6) lies for the most part between the northern end of Vancouver island and the southern end of Queen Charlotte islands and is, therefore, unprotected from the full sweep of the Pacific ocean. Because of this and also because of the high Coast Range mountains the district has an excessive rainfall, averaging in places as much as 200 inches annually. The temperature is, however, very even and, for such high latitudes, rather moderate. There is little frost except at the heads of the longer inlets which are occasionally frozen over. Where the rocky slopes of the mountains are not too steep and where they are protected from strong ocean gales, vegetation is luxuriant and large timber is plentiful up to elevations of 2,000 or 3,000 feet.

The population is sparse, the great majority being employed in the large pulp and paper mills at Ocean Falls and Swanson Bay and their attendant logging camps. The six canneries of the district support a small number of fishermen; the Surf Inlet mine has a camp of over 200 inhabitants; the Drum Lummon mine has a much smaller camp and there are a few prospectors and trappers in the remoter parts. The only arable land is found in the broad valleys at the ends of the larger inlets, and in two of these, namely Bella Coola and Kitimat, there are small agricultural settlements. The six or seven Indian villages in the district contain a population of about 1,000.

Shoreline. The shoreline of this part of the coast is extremely irregular. It consists of an intricate network of channels, bays, and inlets, which form numerous islands and extend far inland; conditions which admirably facilitate a geological study of the district from its shoreline. The channels may be classified into: (1) large fiords 1 to 3 miles in width, which reach inland for 40 to 100 miles; and (2) the smaller but more numerous channels lying closer to the ocean.

The fiords are the most striking feature of the British Columbia coast, and for size and grandeur are unequalled, except, perhaps, by the fiords of Norway. They range in width from 1 to 3 miles. The shores are usually fairly parallel, with few enlargements or constrictions and scarcely any small indentations. They form lofty rock walls so steep as often to appear perpendicular, and generally rising shear from the water's edge to culminate in snow-capped peaks 4,000 to 7,000 feet high. This steepness is as marked below the surface of the water as above. Depths as great as 300 fathoms have been recorded, and even greater depths may exist in the larger fiords, which have not been sounded. Anchorages are consequently few and difficult to find. Some of these large inlets are unusually long. For example, Burke channel extends for 53 miles well into the heart of the Coast range. Dean channel penetrates the range to a distance of over 70 miles. Most notable of all is Gardiner canal, the head of which is about 160 miles from the outer coast. Some of these channels are remarkably straight; others, such as Roscoe inlet and Gardiner canal, are composed of a number of long, straight reaches at rather abrupt angles to one another.

Near the outer coast much smaller channels occur in such numbers that they form a maze of intricate passages surrounding numerous islands. These are narrow, crooked, and shallow with numerous obstructions, and many of them are still unsurveyed. Because of these characteristics and also on account of the strong tides in many of them they are somewhat difficult to navigate. The shores are irregular, low, and rocky, covered with stunted trees and grass.

There are conspicuous marks of glaciation everywhere along the rocky shores in the form of polished surfaces, striations, and grooves. The grooves are the most striking. They are best seen on the vertical cliffs where they are often a foot or more deep and are visible over 1,000 feet above the surface of the water. Whether these great fiords owe their origin chiefly to glacial action is a much disputed problem.

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There is, however, no doubt that during the Glacial period they were filled with ice to a depth of several thousand feet, which, with the rock debris which the ice carried along its sides and floor as it moved for centuries seaward, certainly must have had a great influence in carving them into their present form.

Physiography. Almost the entire area is occupied by the formidable Coast range of the Cordilleran system. The small remaining part of the district is a rolling lowland fringing the outer coast and composed largely of islands. The drop from the high upland of the Coast range[1] to this narrow lowland is very abrupt.

The Coast range has been fully described by Dawson[2] and Bancroft[3]. It extends along the Pacific coast from the delta of Fraser river to the head of Lynn canal, a distance of about 900 miles, and has a width of from 50 to 100 miles. From Fraser river to about latitude 51 it trends about north 60 degrees west, but from this point north it has a direction about north 30 degrees west. This change in direction causes it to diverge farther and farther from the Insular system of the Cordilleras, in which system are included the Vancouver Island mountains and the Queen Charlotte mountains. The rugged granite peaks of this system reach elevations of from 4,000 to 9,000 feet. The elevations decrease towards the shore, gradually at first, then near the mouths of the larger fiords they drop abruptly to the narrow lowland fringing the coast, whose average elevation is less than 100 feet.

The lowland occupies a strip from 10 to 25 miles wide and is composed largely of islands. Some of the low flat islands such as Aristazable, Price, and Swindle are quite large. Those which lie farthest seaward are only sparsely wooded and are said to have considerable land suitable for grazing. Those examined by the writer, however, were found to have little or no soil. In consequence of this and the excessive rainfall the flat parts of the islands are occupied by vast muskegs. Attempts made several years ago to raise cattle on Aristazable island failed.

GENERAL GEOLOGY

This section of the Pacific coast (Figures 5 and 6) consists largely of one great formation, the Coast Range batholith. More than nine-tenths of the area is occupied by the quartz-diorites and related plutonic rocks of this formation. The only rocks older than the batholith are a few relatively small inclusions of highly metamorphosed volcanic and sedimentary rocks now in the form of schist or gneiss. The only rocks of the district younger than the batholith, which is of late Jurassic age, are volcanic dykes of late Pliocene or early Pleistocene age and some tuffs and flows of post-Pleistocene age.

PRE-BATHOLITHIC ROCKS

The pre-batholithic rocks consist of about thirty-five small inclusions a mile or so in width scattered throughout the district, and three much larger inclusions which occur towards the northern part of the district and project beyond it. The largest of these lies in the vicinity of Douglas and Desolation channels, and Gardiner canal, and is probably the southern extension of a large area of schist which lies to the north of the area near Prince Rupert. It is very irregular in shape, has a maximum width—on Douglas channel—of 10 miles, and extends southeast into Gardiner canal for 25 miles. The second largest inclusion lies south of this, outcropping along Fraser and Graham reaches for 21 miles. The smallest of the three inclusions outcrops for 7½ miles along Bullock channel.

[1] According to the Sixteenth Report of the Geographic Board of Canada, the term "Coast range" has been abandoned. The western range of the western belt of the Canadian Cordilleras is to be known as the Insular sytem, and the eastern range of the western belt is to be known as the Pacific system. The Insular system includes the Vancouver Island mountains, the Queen Charlotte mountains, and part of the St. Elias mountains. The Pacific system includes the Cascade, Coast, and Bulkley mountains and some unnamed ranges and groups.

[2] Dawson, G. M., "Report on the Northern Part of Vancouver Island and Adjacent Coast," Geol. Surv., Can.

[3] Bancroft, Austen, J., Geol. Surv., Can., Mem. 23, p. 13.

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The less metamorphosed of these older rocks consist of andesite, basalt, and breccias of a basic composition, all of which contain considerable chlorite, mica, and quartz, and are somewhat schistose. A few more acid varieties occur, for example, on Bardswell islands. Here, very light-coloured pyroclastic rocks are composed of angular fragments of fine-grained feldspathic and siliceous volcanic rocks. In many places, particularly in the southern part of the district, the volcanic rocks are interbedded with beds of limestone from a few feet up to 50 feet in thickness. This association of limestone and andesite is so characteristic of the Vancouver volcanics which are widely distributed along the coast to the south, as to suggest that some, at least, of these remnants belong to that formation. A highly metamorphosed conglomerate containing pebbles of limestone up to 8 inches in size was found on the west shore of Mussel inlet near the south end of Roderick island. The other pebbles consist of metamorphosed volcanic rock, biotite schist, and an acid plutonic rock, composed of plagioclase, quartz, and hornblende, with usually a segregation of pyrite in the centre.

The rocks composing the large inclusions in the northern part of the district are much more highly metamorphosed, and consist of chlorite schist, biotite gneiss, and, in places, garnet gneiss. A schist which contains a considerable amount of finely disseminated graphite occurs in Poison cove, at the head of Mussel inlet.

The strike of the foliation in most of these inclusions conforms in general with the tectonic lines of the district which trend north 10 degrees to 40 degrees west. The most notable exception to this rule is in the large inclusion outcropping along Douglas and Desolation channels, where the strike varies from north 60 degrees to 85 degrees east. The batholithic rocks in the vicinity of the inclusions have a well-developed gneissic structure parallel to that of the inclusions.

All that can be said at present regarding the age of these pre-batholithic rocks is that some of them, which consist of interbedded limestone and andesite, bear strong lithological resemblances to, and are probably related to the Vancouver volcanics of Upper Triassic age.

COAST RANGE BATHOLITH

The Coast Range batholith is the principal geological feature of the coast region of British Columbia. It extends from Fraser river north to Alaska, and has an average width of over 100 miles. It occupies over 90 per cent of the area here described (Figures 5 and 6) and has a width of over 75 miles. Just north of this area there is, however, a marked constriction in the batholith north of which it gradually narrows for the remainder of its length.

The rocks composing this immense intrusion are surprisingly uniform in appearance and composition throughout, and in the district under present consideration the variations were found to be too slight to be mapped. The most typical rock of this section of the batholith is a medium-grained, light grey quartz diorite, consisting of white plagioclase, quartz, hornblende, a varying amount of biotite, little or no alkali feldspar, and, in places, a conspicuous amount of honey-yellow sphene. The plagioclase consists of andesine, or oligoclase-andesine, and very rarely a little andesine-labradorite. Quartz forms from 10 to 25 per cent of the rock and is always one of the later minerals to crystallize. The hornblende, which is a constant and plentiful component, is a peculiar variety and decidedly different from that found in the batholithic rocks to the south. In thin section it is strongly pleochroic from light yellowish green to deep greenish blue, and has extinction angles up to 24 degrees. The hornblende of the batholithic rocks to the south is brownish green with extinction angles up to 14 degrees. The alkali feldspar in the typical quartz diorite does not exceed 1·5 per cent. Biotite is usually present in small amounts and occasional grains of augite are found.

The most common variation of the quartz-diorite is a lighter coloured rock with more quartz, a more acid plagioclase, and decidedly more alkali feldspar, so that it

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approaches granodiorite in composition. Two large areas of such rock were found, one on Labouchere channel and the neighbouring parts of Dean and Burke channels, and the other at the head of Ellerslie channel. The rock of the first-mentioned area is a light grey to almost white, medium-grained granodiorite. It is composed of much quartz, oligoclase, oligoclase-andesine, muscovite, and alkali feldspar, with small amounts of biotite, hornblende, and augite. The alkali feldspar is chiefly orthoclase, some of which is intergrown with the quartz, forming micropegmatite. Considerable microcline is also present, and some anorthoclase. Microscopic quantitative determinations were made of the relative amounts of alkali feldspar and lime-alkali feldspar, by immersing powdered samples of the rock in a liquid with an index of 1·530, which lies between the indices of these two groups of feldspars, and then applying the Rosiwal method. The results showed about four times as much lime-alkali feldspar as alkali feldspar, thus fixing the classification of these rocks in the granodiorite family. The Ellerslie channel granodiorite is similar to this, but has less muscovite, and slightly more orthoclase, giving it a pinkish colour. The Labouchere granodiorite is the only phase of the Coast Range batholith known by the writer to contain a high proportion of muscovite and a relatively low proportion of biotite and hornblende. This quality, together with the beautiful white colour and medium, fine, even grain of the rock makes it a very desirable building stone and superior to any other rock of the batholith.

A hornblende granodiorite, as distinguished from the above biotite-muscovite granodiorite, was found on Mathieson channel. It consists of quartz, oligoclase, andesine, hornblende, microcline, and orthoclase, with a small amount of biotite.

Pegmatitic and aplitic variations are not common in the southern part of the batholith, but in the northern part of this district, in the vicinity of Douglas channel and on Princess Royal island, they are fairly plentiful, and are associated with the gold deposit of the Surf Inlet mine and the copper-gold deposits of the Drum Lummon mine. Along the northwest shore of Douglas channel between Hartley bay and Helen point pegmatite dykes and pipe-like masses of pegmatite are numerous. They are composed of microcline, orthoclase, anorthoclase, oligoclase, albite, perthite, micropegmatite, quartz, and biotite and at the Drum Lummon mine also chalcocite, bornite, chalcopyrite, hematite, and gold. The microcline and orthoclase occur in large pink crystals up to 18 inches in length and were deposited earlier than the quartz. The anorthoclase is in small white to clear euhedral crystals less than an inch in size, and closely resembles the albite, which has a similar colour and appearance and is not always twinned. The biotite forms large thin leaves 8 or 10 inches in diameter, which occupy fractures in the feldspar and quartz. The quartz varies from a small amount up to over 50 per cent of the vein or dyke. It is one of the latest minerals to form and is almost invariably segregated in the central parts of the dykes. In the dyke at the Drum Lummon mine a small cavity in the quartz was found filled with laumontite. This mineral is somewhat irregular in its optical properties, having lower indices of refraction than is normally found and extinction angles up to 45 degrees. Some well-developed crystals were found and measured by E. Poitevin, Mineralogical Division, and several of the typical forms of laumontite recognized, thus proving the identity of the species.

None of the minerals of the rarer elements which are so characteristic of pegmatite dykes were found. The only differences between the pegmatites and the normal country rock are in their coarse texture and much higher percentage of potash and soda.

Basic variations are very uncommon, but occur in the vicinity of some of the more basic inclusions. They differ from the normal rock by having no quartz and a high proportion of hornblende which gives them a dark grey to black colour.

In a great many places the batholithic rocks are strongly gneissic. The foliation is parallel to that of the inclusions, varying from north 5 degrees to 30 degrees west. This gneissic banding is more strongly marked in the vicinity of the inclusions and is particularly well developed in and about the Surf Inlet mine.

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Faulting in the batholithic rocks is commonly found. The most strongly developed fault zone in the district is at Surf Inlet mine. A similar one occurs in Rivers bight, a large inlet on the west shore of Princess Royal island, and about 12 miles to the north. Both of these are strike faults and have shear zones up to 50 feet in width.

The age of the batholith is generally considered to be late Jurassic, but in a few localities its rocks have been found cutting Cretaceous sediments.

BELLABELLA FORMATION

Along the north shore of Denny island, in the vicinity of Bellabella, the batholithic and older rocks are cut by a vast number of peculiar dykes so numerous in places that the older rocks are completely replaced. East of this locality the number of these dykes diminishes rapidly, but westward they occur in considerable numbers as far as Bardswell islands where they again become very numerous. West and north of this place occasional dykes of a similar composition are found as far as Douglas channel. These have been grouped in one formation and named after the nearby settlement, the Bellabella formation.

Throughout the district these dykes maintain vertical dip and a fairly uniform strike of north 5 to 35 degrees west. They are occasionally found cutting one another and in general the more basic varieties are the younger. They vary in width from a foot or less up to 150 feet.

Some of the later members are very similar lithologically to the post-Pleistocene volcanics found on Lady and Lake islands, which lie 16 miles northwest of Denny island and 7 miles north of Bardswell islands. Many of the dykes are composed entirely of amorphous volcanic glass and practically all the others have all the characteristics of surface flows. These facts indicate that the dykes are of recent date and perhaps related to the post-Pleistocene volcanics. Some of the larger dykes have glaciated surfaces, but these are cut by more recent dykes which show no signs of glaciation. It is the writer's opinion that they were injected during a period extending from late Pliocene to late and probably post Pleistocene.

The dykes of this formation have a peculiar and, for this region, a unique petrology. They vary from black diabases or basalts through andesites and trachytes to highly siliceous rhyolites. Many of them are abnormally high in soda and abound in such minerals as riebeckite, ægirine, ægirine-augite, anorthoclase, and albite. They vary in texture from coarse porphyries with phenocrysts up to an inch in length to completely amorphous glass. The majority are exceedingly fine-grained and possess most of the characteristics of surface flows such as trichites, globulites, cumulites, spherulites, amygdules, and flow structures. Many of them are extremely agglomeratic, containing fragments similar to the dykes themselves and also fragments and pebbles of quartz diorite.

The most common type of rock found in this formation, and the only one which is widely distributed in the district, is a dark to black, fine-grained rock which weathers to a buff colour and is composed chiefly of augite and labradorite-bytownite. Dykes of this nature have an exceptionally well-developed columnar jointing. The columns lie horizontally and weather out very perfectly, giving the dyke the appearance of a pile of cordwood. Many examples of this phenomenon occur in the district, and are just as striking and somewhat similar to the famous Devil's Wall of Oschitz, Bohemia.

Microscopically the rock composing these dykes is a medium to fine-grained mixture of clear amber coloured labradorite-bytownite, and clear, glassy, brownish or greenish, augite with considerable associated brownish glass in the intercrystal spaces and in veinlets in the augite and feldspar crystals. It is this glass which gives the rock its peculiar brownish colour. The glass occupying the intercrystal spaces is somewhat devitrified and characterized by minute radial and concentric structures. The feldspars frequently contain very fine acicular crystals too minute to identify but which are probably pyroxene.

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Another rock type similar to this but decidedly porphyritic is also found abundantly. In this type the phenocrysts are mainly of clear, fresh labradorite, but there are also phenocrysts of albite which are thickly clouded with sericite and in the outer portions are graphically intergrown with the groundmass material. Augite also forms phenocrysts up to an inch in size. In the hand specimens these are dark brownish-green and of glassy lustre, but under the microscope they are seen to be replaced by serpentine glass and groundmass material. The groundmass consists of augite, andesine, and labradorite.

A rock somewhat similar to the above in composition but very different in appearance, and in some respects a very unusual rock, was found in a dyke 60 feet wide on Tree island, just north of Denny island. It consists of large, clear, glassy phenocrysts of feldspar up to an inch in length, so numerous as to constitute over 50 per cent of the volume of the rock, enclosed in a fine, dense, dark brown groundmass. A few equally large phenocrysts of augite also occur but these are much shattered and corroded. The feldspar phenocrysts consist of bytownite and anorthite, principally the latter, in which the anorthite component is often well over 90 per cent. These phenocrysts are clear and glassy except for included veinlets and blebs of volcanic glass and groundmass material. Like the above rocks this one also contains feldspar phenocrysts of a much more acid type, such as oligoclase and andesine, which are densely clouded with sericite and an opaque alteration product which is frequently graphically intergrown with the feldspar, particularly along the margins of the crystals. The groundmass consists of labradorite, andesine, augite, much brownish glass, and a still larger amount of brownish, opaque material in the form of grains and rods, which probably consist largely of iron oxide.

There are many dykes composed of a dense, dark-bluish groundmass that contains fragments of similar material, fragments of quartz and feldspar, and a great many small, peculiarly-shaped, yellowish-green masses. Many of these yellowish-green bodies are angular; others are spherical or ellipsoidal and arranged in straight parallel rows about one-quarter of an inch apart; still others form spherical shells up to 1 inch in diameter which are filled with groundmass material, but often have at their centres small clusters of quartz or feldspar fragments. Under the microscope the feldspar is seen to consist of orthoclase, albite, anorthoclase, and much microperthite. The yellowish-green areas are so extremely fine grained, that their composition could not be determined, but epidote seems to be one of the components. The angular rock fragments consist of micropegmatite, glass, riebeckite, biotite, ægirine-augite, ægirine, and spherulites composed of radial intergrowths of quartz, feldspar, and riebeckite. The groundmass is a cryptocrystalline aggregate of riebeckite, quartz, and feldspar, and has a perfectly developed flow structure curving around the larger crystals and rock fragments. The quartz encloses ægirine-augite, riebeckite, and magnetite. The rare mineral ænigmatite was found as small phenocrysts in these rocks. Small epidote veinlets were found in a few specimens.

Lighter-coloured varieties of these dyke rocks are plentiful in which the proportion of riebeckite is much less and quartz and feldspar, both as phenocrysts and groundmass, are much more abundant. They are light bluish grey and decidedly porphyritic. These rocks are evidently sodic rhyolites and closely resemble tauralite or comendite.

Some of the light-coloured dykes have ægirine and ægirine-augite as the principal coloured constituent instead of riebeckite. They are medium rather than fine-grained, have a light grey colour with a greenish rather than bluish cast, and are only slightly porphyritic. They are usually quite porous and some of them are slightly banded. They consist of abundant quartz, orthoclase, micropegmatite, ægirine, and ægirine-augite, with small amounts of albite, microcline, anorthoclase, arfvedsonite, and riebeckite. In one of these rocks small prisms of ægirine occur on the walls of spherical vesicules and project towards the centres of the cavities.

A few dykes of a very light colour are composed of quartz, orthoclase, biotite, and oligoclase.

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POST-PLEISTOCENE VOLCANICS

On Lake and Lady islands, in Mathieson channel, is a considerable thickness, but small area of stratified volcanic tuff and some flows. These lie on the glaciated surface of the batholithic rocks and were evidently ejected in post-Pleistocene time. Small flows of similar rocks are found on Bardswell islands, on Price island, and on Swindle island. These other occurrences consist of flows with no tuff, and their relation to the glaciated surface was not discovered. However, they are nowhere glaciated themselves, the thin flows conform to the present topography, and they have strong lithological similarities to the Lake Island volcanics. For these reasons it is thought that they belong to the same post-Glacial period of eruption as those found on Lady and Lake islands. All the extrusions occur close to a line striking north 50 degrees west through the south end of Lake island.

Lake island is about a mile wide and 2 miles long and is situated about 3 miles above the entrance to Mathieson channel. Its shores, except at two places, are composed of quartz diorite, quite flat and strongly glaciated. Covering the whole central part of the island is a conical mountain nearly 1,000 feet high composed entirely of brownish volcanic tuff. On the east shore of the island the tuffs clearly rest on the flat glaciated surface of the quartz diorite. On the north shore, large, well-rounded boulders of quartz diorite up to 6 feet in diameter and with a pronounced tendency to exfoliate are found buried in the tuffs. On Lady island, which lies a mile to the west, similar tuffs are found. Here they have a maximum thickness of about 60 feet and in three different places they were found lying on glaciated surfaces of the quartz diorite. At the base of the formation in several places numerous large glacial boulders were found, and in one place the tuffs rested on a small bed of till.

These tuffs are well bedded and generally horizontal. In some places, however, they have gentle depositional dips seaward conformable to the surface on which they rest.

They consist of rock fragments, usually of quartz diorite, a large amount of brownish, partly devitrified, spherulitic and pumaceous volcanic glass; a large amount of clean amber-coloured augite in the form of broken crystals often having a rim of glass frozen to them; fragments of quartz, hornblende, and a great many rounded phenocrysts of beautiful yellowish, glassy labradorite—a very characteristic mineral and invariably found in all the above-mentioned occurrences of recent volcanic rock.

The flows on Price and Swindle islands are from 20 to 100 feet thick and have a beautifully developed columnar jointing. They have an exceedingly fine-grained, dense black groundmass, enclosing a large number of the yellowish, glassy labradorite and augite phenocrysts, similar to those found in the tuffs of Lady and Lake islands. The groundmass consists of minute rods of augite and laths of labradorite, with which is mixed a large amount of fine magnetite which gives the rock its black colour. A small amount of glass containing spherulites is present, some chlorite, and a small amount of highly pleochroic, bluish-green amphibole.

ECONOMIC GEOLOGY

Gold, silver, copper, and iron occur in this district (Figures 5 and 6). Large quantities of gold and some silver and copper have been produced, and are still being produced, by the Surf Inlet mine on Princess Royal island. Small quantities of copper, gold, and silver have been produced by the Drum Lummon mine, on Douglas channel, and a few tons of magnetic iron ore have been shipped from a deposit on Dean channel. Small, gold-bearing quartz veins at several other localities on Princess Royal island and on the adjacent mainland have, so far, proved to be of no commercial value. Small deposits of copper with associated gold occur also on Klekane inlet, on the south end of Gribbell island, on Kemano river, which flows into Gardiner canal, and on the river which enters at the head of Kutze inlet. The deposit in Klekane inlet is being worked in a small way. That on Gribbell island has been extensively

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developed, but is now abandoned. The deposit on Kemano river is in the early stages of prospecting, and the deposit in Kutze inlet has been considerably explored and is equipped with several miles of tram-line. It is reported to have promise as a copper and gold producer.

SURF INLET MINE

The Surf Inlet gold mine, owned and operated by the Belmont Surf Inlet Mines, Limited, is situated about 7 miles inland from the head of Surf inlet, on Princess Royal island. The mine is 1 mile from Bear lake, which is 1 mile above Cougar lake, and Cougar lake extends to within 200 yards of the head of Surf inlet. By the construction of a dam at the outlet of Cougar lake its level was raised to that of Bear lake and a good water route for tugs was established between the dam and the landing at Bear lake. From this landing an electric tram-line runs to the mine, and from the head of the dam to the bunkers at the beach there is an incline cable tram operated by an electric winch.

The dam also creates a sufficient hydrostatic head for a hydro-electric generating plant situated at the beach, and capable of supplying power for all purposes about the mine. A well designed mill with a capacity of 300 tons a day is used to concentrate the ore.

This deposit, though discovered many years ago, began producing on a large scale only in 1917. It is now one of the important gold producers of the province and in 1920, 108,082 tons of ore were mined, yielding 9,687 tons of concentrates which gave 44,051 ounces of gold, 20,104 ounces of silver, and 685,259 pounds of copper. The mine is now developed down to the 1,000-foot level and has approximately 50,000 feet of underground workings. An adjoining property, known as the Pugsley, recently acquired by the Belmont Surf Inlet Company, is now being developed and will soon commence producing.

The equipment and layout of this property has been fully described by Geo. A. Clothier in the report of the Minister of Mines of British Columbia for the year 1919.

The ore-bodies, which are large pyritized quartz veins in a zone of intense shearing in the rocks of the Coast Range batholith, outcrop on either side of a deep, U-shaped valley. The Surf Inlet ore-bodies are on the north and the Pugsley on the south side. The shear zone strikes a few degrees east of north and intersects the valley at nearly right angles. The veins dip from 45 degrees to 60 degrees to the west, hence the outcrops of the ore-bodies trend northeasterly up the north side of the valley and in a southeasterly direction up the south side. The valley, though only about 3 miles in length and less than half a mile wide, has, nevertheless, a depth of over 3,000 feet, and its walls are so steep that in places they appear to be almost perpendicular. The upper end of the valley, which terminates abruptly amid steep mountains, is occupied by Paradise lake. The lower end opens into the broad valley occupied by Cougar, Bear, and Deer lakes. The main haulage, of 550-foot level of the Surf Inlet mine, is at an elevation of 538 feet, or about 450 feet above the bottom of the valley; that of the Pugsley is about 30 feet above the tram-line which runs to the landing on Bear lake.

The ore of the Surf Inlet mine occurs in large pyritized quartz veins in places 37 feet in width. These lie in a zone of intense shearing which cuts the rocks of the Coast Range batholith in a direction about north 3 degrees east and for a distance passes through an inclusion of chloritic schist whose foliation and contacts also strike approximately parallel to the shear zone. The veins are in general parallel to the shearing and dip from about 40 to 60 degrees to the west. They have a maximum length of 1,000 feet and a width of 40 feet. There are, however, cross veins which lie more or less perpendicular to this direction. One of these cross veins, lying between the 550-foot and the 200-foot levels, is of considerable size and importance. The only other rocks in this vicinity are two small pegmatite dykes on the 550-foot level and a black basic dyke which cuts the ore on the 100- and 200-foot levels.

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Inclusions of older rocks in the form of schist and gneiss occur at several places in the vicinity of the deposits. A fairly wide band of gneiss with a north 30 degrees west strike and 90 degrees dip occurs in the cuts along the tram-line about 600 feet west of the Pugsley lower tunnel, and what appears to be a continuation of this band occurs on the cliffs at the opposite side of the valley a considerable distance west of the main dump of the Surf Inlet mine. A large band of schist occurs on the surface above the upper levels of the Surf Inlet mine and extends down through the mine to the lower levels. A similar band also occurs on the surface above the Pugsley mine.

On the 50-foot level of the Surf Inlet mine the country rock consists entirely of schist, though quartz diorite occurs a short distance south of the portal. On the 100-foot level the schist is still the dominant country rock, though a wide band of quartz diorite occurs in No. 1 east crosscut and in recent workings in the southern part of this level. On the 200-foot level there is about an equal amount of quartz diorite and schist, the schist occurring chiefly along the contacts of the west vein and large cross vein, the diorite as the principal wall-rock of the east vein. On the 320-foot level the schist forms only a small part of the country rock, but is found adjoining the widest and richest part of the west vein and to a less extent in the vicinity of the large cross vein, which has a width of 31 feet on this level. On the 420-foot level the schist is still less in amount and is found adjoining both the east and west veins, but is most abundant at the north end of the west vein where it has its greatest width. On the 550-foot level where the ore reaches a maximum in both width and values, there is very little schist to be found, the only body of any account being on the hanging-wall towards the northern end of the west or main vein, and beyond this in west crosscut No. 6. Below this level only very small bodies of schist occur, and these lie in the northern extremities of the workings. It is evident, therefore, that the schist lies in general in the west or hanging-wall and pitches to the north, whereas the veins pitch to the south. In the Pugsley mine it is likewise found mostly in the higher workings. In general it may be said that slightly higher values are found where the veins lie in schist than where they lie in quartz diorite.

The schist is a dark greenish, medium fine, strongly schistose rock, grading in places into gneiss. It consists chiefly of chlorite, sericite, and talc with small amounts of quartz, andesine, apatite, augite, and, in the vicinity of the veins, considerable ankerite.

The batholithic rocks in the mine and its vicinity consist entirely of quartz diorite. They are fairly coarse-grained and are strongly gneissic, the foliation being generally parallel to the veins. They consist of quartz, andesine, and green hornblende with small amounts of biotite, augite, and sphene. On the 900-foot level of the Surf Inlet mine the quartz diorite contains besides the above minerals small amounts of oligoclase-andesine, orthoclase, and micropegmatite, and has a slightly higher proportion of the biotite and sphene than is ordinarily found in the quartz diorites of this district. The proportion of orthoclase is, however, too small to place this rock in the granodiorite family.

The pegmatite dykes occur on the 550-foot level, 900 feet from the portal and 200 feet from the nearest vein. These dykes which are only a foot or two in width are exactly like those found at the Drum Lummon mine and elsewhere along the coast. They are composed of orthoclase, microcline, anorthoclase, albite, oligoclase, quartz, and biotite. The two pegmatite dykes in the Surf Inlet mine have a smaller proportion of quartz than most of the other pegmatites of the district. The relation of these dykes to the veins is not known, but as some of the veins carry small amounts of albite, orthoclase, and microcline, and the pegmatites at the Drum Lummon mine carry sulphide of iron and copper as well as some gold, it would seem that the veins and pegmatites are very similar in composition, and, therefore, probably closely related in origin.

The ore occurs principally in two large quartz veins, one on the west or hanging-wall side, and the other on the foot-wall of the shear zone. In the upper levels, the

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veins are from 100 to 160 feet apart, but gradually converge until they meet at the 550-foot level to form one large vein which persists to the lowest levels. The veins dip to the west from 40 to 60 degrees with an average of about 45 degrees. Above the 550-foot level the dips are much more irregular than below it, a feature which may help to explain the occurrence of higher values above than below this level. Above the 550-foot level the two veins are connected by a large cross vein, in places 35 feet wide, which strikes almost at right angles to the main veins and dips nearly vertically. Besides these there are numerous small veins in the fractures and shear planes of the diorite. These strike in all directions.

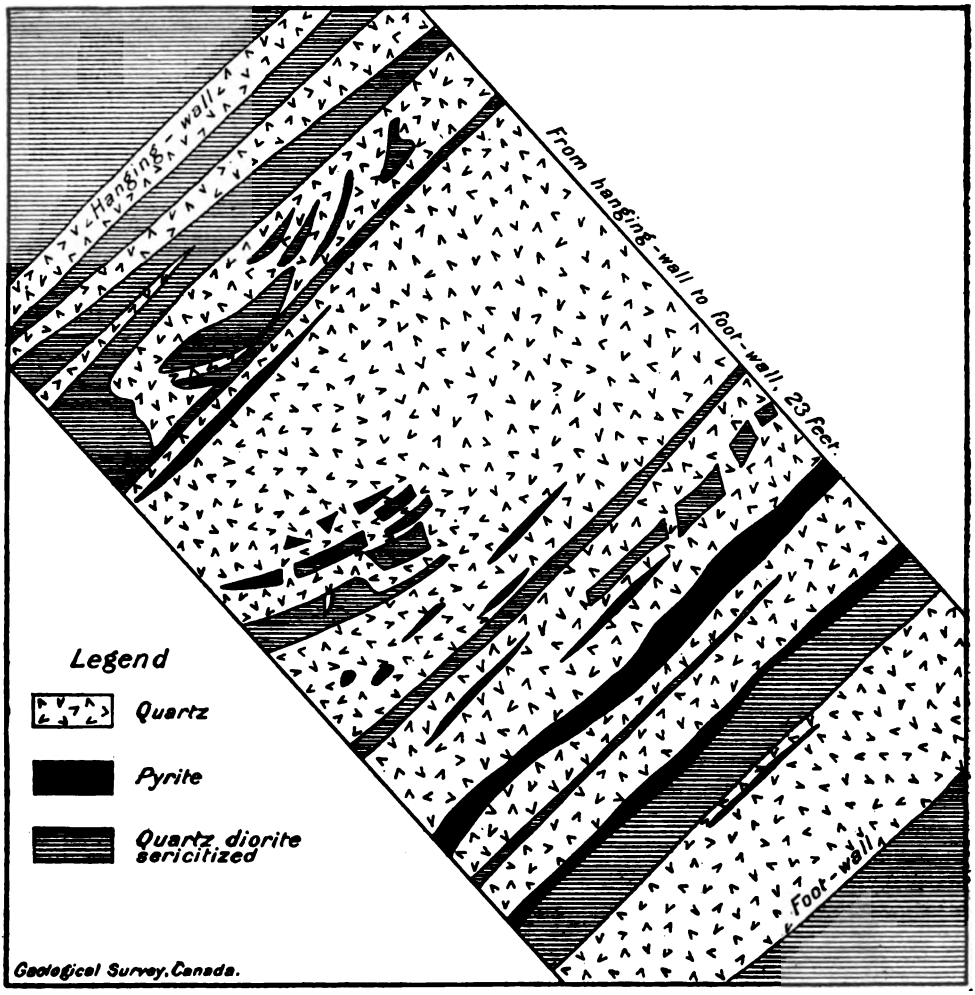

Figure 7. Section of vein exposed in stope No. 4, between 550- and 700-foot levels, Surf Inlet mine.

The margins of the veins are almost invariably made up of a number of alternating bands of quartz and sericitized country rock, lying parallel to one another and to the vein walls and ranging in width from several feet down to a few inches. Large angular blocks of sericitized country rock also are found scattered irregularly through the quartz veins and are more or less silicified, in some cases so completely that only mere shadows of the original blocks remain. The pyrite usually lies in streaks and bands parallel to and sometimes adjacent to, the bands of included country rock, as shown in Figure 7.

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The lengths of the main veins vary from 100 feet up to a maximum of 1,000 feet on the 550-foot level, and the width from 2 or 3 feet up to 40 feet. The axes of the ore-body pitch to the south 45 degrees.

The veins consist chiefly of quartz and pyrite, the latter carrying the gold. After these the most conspicuous mineral is a creamy white ankerite found abundantly in places, particularly at the extremities of the veins, where they pinch out. It is usually associated with considerable chlorite and sericite. Other gangue minerals occurring in small amounts are hornblende, mariposite, calcite, dolomite, and kaolin. On the 100-foot level there is a vein which is decidedly pegmatitic in character and contains microcline, orthoclase, albite, albite-oligoclase, biotite, and small quantities of magnetite. A narrow band in the altered schist on the 550-foot level consists of calcite, andradite, and pale green translucent diopside, and probably represents a band of metamorphosed limestone in the schist. The metallic minerals, other than pyrite, are chalcopyrite, native silver, chalcocite, bornite, covellite, hematite, and molybdenite. Small quantities of malachite and azurite are now forming on the walls of the stopes and tunnels.

Quartz is exceedingly abundant throughout the deposits, and at certain places, such as on the 550-foot level, there are solid masses of almost pure quartz nearly 40 feet in width. It is slightly milky in colour, and is composed of an aggregate of very fine anhedral crystals. These contain many minute inclusions of foreign matter, some of which are liquid or gaseous, whereas others are solid and clear or opaque, but too minute to identify. The quartz was deposited throughout a long period in the earlier stages of the formation of the deposit.

Ankerite is widely distributed in the mine but is usually more abundant in the schists than in the quartz diorite. It has an unusually light colour varying from pure white to cream or pink, and only very rarely has it the grey colour so common to this mineral. In places it forms very fine-grained masses, but usually it is coarse grained with large, curved cleavage faces. It was deposited during a considerable period of time, some of it being earlier than the quartz and some of it later, the fine-grained masses usually being earlier.

Chlorite in the form of scattered films and veinlets is plentiful and is as a rule associated with the ankerite.

Sericite is exceedingly abundant throughout the mine. The quartz diorite close to the veins, and the blocks of it included in the veins, are frequently altered to aggregates of pure sericite. Alteration, however, never extends more than a few inches, or a foot at most, from the veins. In some cases the flakes of mica are sufficiently large to be called muscovite.

Hornblende was found in small quantities associated with quartz and sericite.

A bright greenish coloured mica with optical properties closely approximating those of mariposite, or chrome mica, was found in small quantities on the 900-foot level, where it is associated with calcite, quartz, ankerite, and pyrite.

Calcite in small amounts is found in all parts of the mine and under various conditions. That associated with the diopside and garnet is probably residual from a limestone band in the schists. In other places it forms small veinlets cutting the latest ore minerals.

A small amount of dolomite was found on the 550-foot level associated with chlorite and small flakes of hematite.

Kaolin occurs in the gouge of the sheared diorite, sometimes in considerable amounts.

Orthoclase, microcline, albite, albite-oligoclase, and biotite were found only in the pegmatites on the 550-foot level and in a small vein on the 100-foot level. Albite occurs also at a number of places in the quartz veins.

Diopside and grossularite were found only in the small band of altered limestone mentioned above.

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Pyrite is very abundant and is the chief ore mineral, but is much less plentiful than quartz. In the richest parts of the veins the pyrite would not constitute more than 25 per cent of the total volume. It occurs in streaks parallel to the strike and usually adjacent to the sericitized wall-rock, or to large sheets of the altered wall-rock now included within the quartz veins. A small amount of it occurs in rounded masses or as very irregular cross veinlets in the central parts of the quartz. The mode of occurrence is shown in Figures 5 and 6.

The pyrite is usually massive but in numerous places it is also coarsely crystalline, forming strongly striated, truncated cubes. It is very light yellow and except for small veins of chalcopyrite and blebs of native silver it appears quite homogeneous under the highest power of the microscope. All the gold is known to be contained in the sulphides, as the siliceous tailings from the concentrating mill contain not even a trace of gold. However, though the gold content is rather high, no gold could be found under the microscope. It must, therefore, occur in the sulphides in an extremely fine state of division, if not in solid solution or chemical combination. The silver—not nearly as plentiful in the ore as the gold—can be seen in considerable quantities under the microscope. The pyrite was deposited over a considerable length of time and is older than some of the quartz and younger than other portions of it. It is, however, unquestionably much the earliest of the metallic minerals.

Chalcopyrite is found plentifully in all parts of the mine, but is not always visible to the naked eye. It occurs as veinlets cutting the pyrite crystals and gangue minerals, and was deposited during a later period than the pyrite, quartz, and other gangue minerals.

Bornite was found in only minute quantities in a specimen from the 340-foot level. It forms small, sharply defined veins in the chalcopyrite and is clearly much later in origin.

Chalcocite was found in minute quantities intergrown with the bornite and also as small veinlets in the chalcopyrite. It is later than the chalcopyrite but not all of it is later than the bornite.

Native silver was found in the pyrite and chalcopyrite in the form of rounded blebs. It forms veinlets in the pyrite and is undoubtedly much later in origin than this mineral. In no place, however, does it form veinlets in the chalcopyrite. It occurs as rounded or irregular masses in the chalcopyrite which shows that it was not deposited later than, but probably simultaneously with, that mineral.

Covellite was found in minute quantities on all the levels of the mine and invariably replaces the chalcopyrite veinlets. It is one of the latest minerals formed and is very likely due to the action of surface waters which flow freely through the shattered vein material.

Malachite and azurite are forming rapidly on the walls of the tunnels and stope.

The veins of the Surf Inlet mine were formed by solutions which originated in the uncooled parts of the batholith and percolated up through the shear zone in which the veins occur. In so doing the solution sericitized the country rocks and replaced them by quartz, pyrite, and other minerals. The earliest solutions deposited quartz, pyrite, and ankerite. Later solutions deposited chalcopyrite and native silver, and still later solutions deposited bornite and probably some chalcocite. After this the veins remained unchanged until a recent date, probably after the Glacial period; when surface waters found their way down through the shear zone and replaced small quantities of the chalcopyrite and bornite by covellite and probably chalcocite. As the gold could not be seen it is not known at what stage it was deposited, but it was most probably deposited simultaneously with the pyrite in which it occurs.

The distribution of the values in that part of the deposits already worked show that they were highest where the veins had their maximum width. The country rock seems to have had some influence in precipitating the metallic minerals and in general the values are slightly higher in the schist than in the diorite. The highest

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values were found where the dips and widths of the veins were most irregular, and the lowest values were found where the dips and widths were most regular. It would, therefore, appear that these were important factors in the distribution of the values.

OTHER GOLD DEPOSITS

Other gold prospects have been staked at several localities on Princess Royal island, the most promising of which is one located and owned by Mr. Wells, one of the original owners of the Surf Inlet. This claim is situated on the steep side of the precipitous mountain which stands just west of the point where Paradise creek enters Bear lake, and three-quarters of a mile from the camp at Surf Inlet mine. The outcrop occurs in a small gulch on the north side of the mountain at an elevation of about 2,180 feet or about 2,000 feet above Bear lake. The surface showing consists of several small irregular veins of quartz which converge to form a large mass up to 12 feet in width and lying in unaltered and only slightly sheared quartz diorite. Below this point a drift adit was driven for over 300 feet. This exposed a well-defined quartz vein about 4 feet in width carrying pyrite, and similar in every respect to the Surf Inlet veins.

The claim which attracted the most attention during the field season is located on the southern arm of Rivers bight, and is known as the Cordilla group. It is owned by David Cordilla, J. Koski, and others, of Swanson Bay. The deposit is a small, much broken quartz vein in a large, intense shear zone, striking north 25 degrees west and dipping vertically, in the quartz diorite of the Coast Range batholith. It has attracted much attention because of its proximity to, and similarity to, the Surf Inlet. Several assays have been made, some of which are reported to have shown good values, in one case up to $9 a ton. This property was sampled at two points by the writer in company with Mr. Cordilla, the principal owner. One of these samples taken near the tunnel contained no gold or silver, and the other, taken at a point 150 feet higher than the tunnel, showed no gold and a trace of silver.

A property known as the Malcolm claim, situated on the northeast of Princess Royal island, about 5 miles north of Swanson bay, and just opposite Kutze inlet, is reported to carry free milling gold. The vein is situated at an elevation of about 480 feet and about half a mile from the beach. It consists of a small but persistent quartz vein ranging from 4 inches to 12 inches in width lying in biotite-sericite schist. It strikes parallel to the schist, north 22 degrees west, and dips northeast 36 degrees. In the face of one of the small tunnels there is exposed a quartz-diorite dyke. The vein contains besides quartz, considerable pyrrhotite and some pyrite, but no free gold could be seen.

On the opposite side of Fraser reach and about a mile south of this property, there is another gold prospect on which considerable work has been done, and which was at one time owned by J. Plattenberger, of Swanson Bay. The deposit is situated at an elevation of about 600 feet above and about one-half mile from the east shore of Fraser reach. It consists of a pyritized band in sericite schist from 4 to 6 feet wide striking north 10 degrees west with a dip of 54 degrees northeast. This pyritized band has been traced for over 1,000 feet and has every appearance of being a good deposit. Fair values have been reported, but a sample taken by the writer contained no silver or gold.

DRUM LUMMON MINE

From the standpoint of production the Drum Lummon (Figure 8) is the second most important mine of the district, having produced in 1919 and 1920 (according to the reports of the Minister of Mines of British Columbia for those years) 355 ounces of gold, 1,281 ounces of silver, and 59,559 pounds of copper. Owing to a number of causes, however, these metals were produced at a loss and during the greater part of 1921 no mining was done on the property. The original company, the

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Drum Lummon Copper Mines, Ltd., was reorganized into a new company registered as the Drum Lummon Mines, Ltd., and placed under the management of Glenville A. Collins, of Vancouver. At the time of the examination the new company was carrying on a small amount of development work in preparation for reopening the mine, but it will probably be some time before production is again resumed.

The camp and workings are situated about 4,000 feet from the shores of a small bay on the west side of Douglas channel, about 100 miles southeast of Prince Rupert. Hartley bay, at the entrance to Douglas channel, and about 26 miles from the mine,

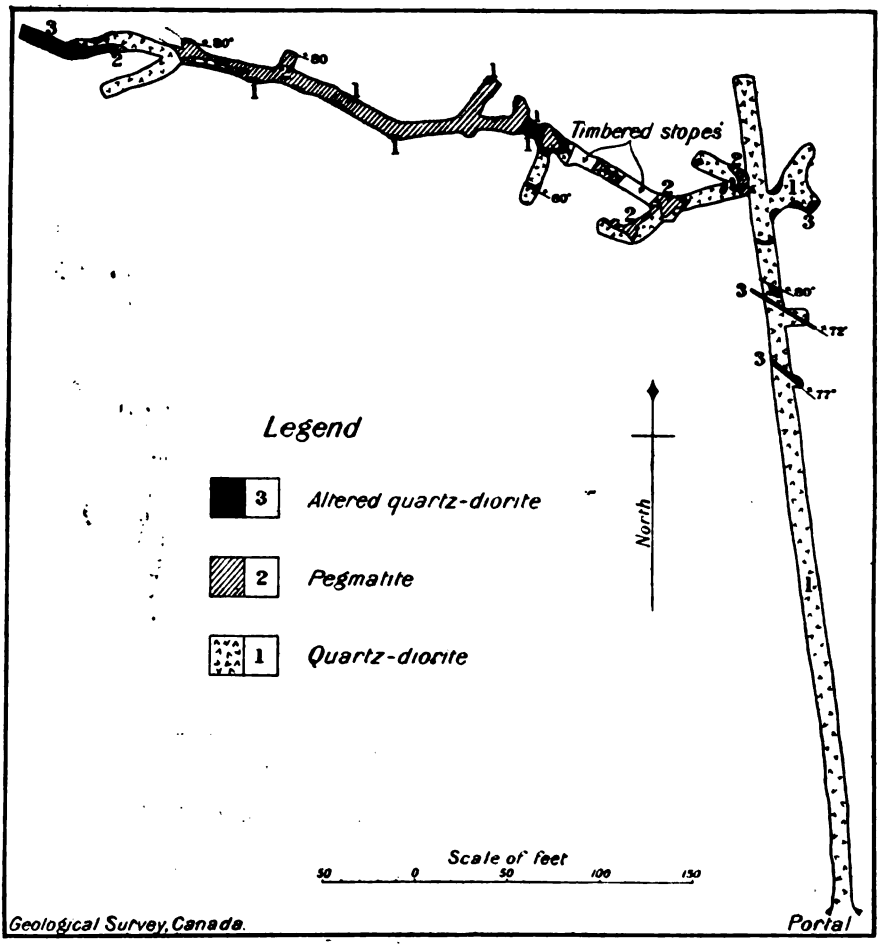

Figure 8. Geology of the Drum Lummon mine.

is the nearest port of call on the steamboat route between Prince Rupert and Vancouver. The tunnel is about 400 feet above sea-level and a good wagon road connects it with the beach, so that transportation problems are unusually simple.

The surface showings occur in the canyon of a small creek, and consist of three pegmatite dykes carrying chalcocite, bornite, and chalcopyrite. The largest of these forms an irregular mass about 20 feet in diameter with narrow dykes extending from either end. The second largest showing lies 70 feet farther up the creek. It is about 8 feet wide and extends across the canyon and west for some distance. The third showing is quite small and occurs high up on the east side of the canyon about 220 feet above the second showing and is similar in character to the others. Several

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bands of aplitic material also occur in the canyon, and, though they contain no metallic minerals, they are, nevertheless, very similar to the altered rock found at the contacts of the mineralized pegmatite dykes.

The underground work consists of a 440-foot crosscut tunnel which intersects a large dyke of pegmatite at a distance of 360 feet from the portal; a somewhat crooked drift which follows the pegmatite to the west for about 400 feet; two small stopes and a vertical raise which goes up through quartz for 100 feet.

The only rocks in the district are the rocks of the Coast Range batholith which occupy virtually the entire area, and, in addition the pegmatite dykes, an insignificantly small inclusion of schist, and a very fine-grained grey dyke of recent origin occurring at the smallest of the three surface showings.

The batholith at this point consists of coarse-grained quartz diorite composed of quartz, oligoclase, andesine, hornblende, biotite, and small amounts of orthoclase, microcline, and bright yellow sphene. Along the contacts of the pegmatite dykes the quartz diorite is altered to a fine-grained, light grey or pinkish rock resembling an aplite, and consisting of quartz, oligoclase, albite, orthoclase, microcline, green mica, and a few small crystals of micaceous hematite. This altered rock forms persistent bands up to 6 feet in width lying along the contacts of the pegmatite dykes. Where the dykes contain little or no feldspar and are composed chiefly of quartz the adjoining country rock is invariably altered to sericite in a manner similar to that at the Surf Inlet mine. Altered rock of the former, or aplitic type, occurs at several places in the mine at distances as great as 100 feet from the pegmatite. These bands are very straight and uniform in width and are developed along well-defined joint fissures, and appear to have been developed by pneumatolitic action similar to that which formed the pegmatite.

The small dyke which occurs at the smallest of the three surface showings is composed of small, rare quartz phenocrysts in a microcryptocrystalline groundmass containing sericite, feldspar, iron oxide, chlorite, and other minerals too fine to determine. The dyke is later than the ore and had, therefore, no influence on its formation.

The pegmatite dykes are similar to those occurring along the shore of Douglas channel north of Hartley bay, and also to those at the Surf Inlet mine. Those at the Drum Lummon, however, are much larger and more irregular in shape. The dyke exposed in the drift and stopes varies from 1 up to 50 feet in width, and there are several smaller masses separated from the main dyke but adjacent to it. Many inclusions of country rock occur in the dyke, some of which are 40 feet long. The dyke has been traced by the drift for 340 feet, but at this distance from the crosscut tunnel the drift passes through the south wall of the dyke and the last 80 feet are not in the dyke. This part of the drift, however, exposes an altered quartz diorite like that adjoining the dyke, thus strongly indicating that the pegmatite lies not far to the north. The dyke, therefore, has a proved length of 340 feet, but is most probably much longer. Its vertical extent has been proved for 100 feet above the tunnel by the raise and in all probability it extends for a great distance below this level.

The gangue minerals named in the order of their abundance are quartz, orthoclase, microcline, biotite, albite, and anorthoclase; and the metallic minerals are chalcocite, bornite, chalcopyrite, micaceous hematite, magnetite, gold, and silver.

The quartz greatly exceeds in amount all the other minerals, in places forming solid masses 40 feet wide. Its situation in the central parts of the dykes with the feldspars and metallic minerals on its margins is invariable. In appearance the quartz strongly resembles that of the Surf Inlet vein. It has a clear to milky colour and is composed of an aggregate of small anhedral crystals containing many inclusions.

The feldspars are all closely associated with one another and constitute about 30 per cent of the total volume of the dykes. They are invariably situated along or near the margins of the dykes, or around the margins of masses of country rock included in the dykes. They are also present in large amounts in the altered country rock

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adjoining the dykes and the altered bands of rock bordering joint fissures. Orthoclase and microcline are the most abundant and occur as large, well-formed pink crystals up to 18 inches in length. Albite and anorthoclase are plentiful, but form much smaller crystals. The feldspars contain many veinlets of quartz and were, therefore, deposited earlier.

The biotite varies from dull grey to black and forms large, thin leaves up to 10 inches in diameter which occupy fractures in the quartz and feldspar.

Laumontite was found in veinlets cutting the altered country rock in the vicinities of the dykes. It was deposited much later than the sericite and other alteration products. This mineral was also found in vugs in the quartz of the central parts of the dykes.

The metallic minerals form a small proportion of the total volume of the dyke, large parts of it being free from ore minerals. Other parts, however, contain lenses of almost pure bornite and chalcocite up to 4 feet in width. They lie, as a rule, on the margins of the dykes between the feldspars and the wall-rock, but occasionally small masses of sulphide are found in the quartz. Considerable sulphide is also found in the wall-rock.

Chalcocite and bornite in nearly equal proportions constitute over 90 per cent of the ore minerals. Chalcopyrite occurs in small quantities and native gold and silver in quantities still smaller. The gold in places is coarse, forming nuggets, but is sporadically distributed. Micaceous hematite is fairly plentiful but was deposited much earlier than the other metallic minerals. Pyrite, as in most bornite-chalcocite deposits, is conspicuously absent.

All the metallic minerals were deposited much later than the gangue minerals.

From the above description, it is evident that this deposit is of an unusual type, being one in which chalcocite, bornite, silver, and gold are associated with an acid pegmatite dyke. The pegmatite was formed from the residual liquor that resulted from the more or less complete crystallization of the magma which formed the Coast Range batholith. From these residual liquors, which were undoubtedly rich in water, the minerals—feldspar, hematite, quartz, and biotite—were deposited in the order named. The minerals were formed at temperatures considerably above the critical temperature of water (365 degrees C.) and, therefore, when the depositing solutions were in a gaseous state. The chalcocite, bornite, and other metallic minerals were deposited by relatively cool liquid solutions which found their way into the pegmatite at a very much later date and after the temperature had fallen considerably below 100 degrees C. The fact that these solutions formed only a very small amount of chalcopyrite and no pyrite indicates that they had a relatively low proportion of iron.

Surface enriching solutions may have had some influence on the ore and may have deposited some of the native silver and chalcocite, but it is not likely that this ore has been enriched to any appreciable extent.

At present the Drum Lummon mine is unproductive and at the time of the examination very little ore could be seen in the workings. What was seen, however, was very high grade and no doubt good sized shoots of similar ore have been mined. There is still a large amount of pegmatite unprospected that probably contains shoots of ore similar in size and amount to those already mined. They will, however, be scattered and disconnected which will add considerably to the cost of mining.

OTHER COPPER DEPOSITS

The only other copper deposit being worked in the district is one known as the Bolton group. It is under a working bond to A. McLeod and associate, of Vancouver, who were engaged, at the time of the writer's visit, in building a sleigh road for the high-grade ore. The property is situated at an elevation of 2,150 feet and about 2 miles north of the shore of Klekane inlet, which lies about 100 miles south of Prince Rupert. The deposit is of the contact metamorphic type, formed in limestone near the

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contact of an intrusion of quartz diorite of Coast Range batholith age. The limestone forms a bed about 7 feet in width interbedded with chloritic schists all of which are steeply folded, strike north 60 degrees west, and dip vertically. The contact of the quartz diorite is exceedingly irregular and surrounds the limestone on three sides. The limestone is altered into the usual minerals epidote, actinolite, hornblende, augite, quartz, and garnet, and for a width of about 18 inches is heavily mineralized with chalcocite and bornite, making fairly high-grade ore. The ore can be traced over an horizontal distance of 100 feet and a vertical distance of 60 feet, but over most of this distance the ore-shoot is quite narrow and much of it is of fairly low grade. Mr. McLeod reported that there was a lead in the schist which assayed $125 a ton in gold, but this could not be found.

On Gribbell island, near the southeast corner, there is a copper deposit of the same type, which was extensively developed in the years 1900 to 1906 during which time $30,000 was spent on equipment and development work. The project failed owing to the irregularity and low value of the ore.

The mine is at an elevation of 1,200 feet, and about 1 mile from the beach, with which it is connected by a corduroy road still in a fair state of repairs. A boiler house, compressor, and fairly large camp still remain, but these are in a dilapidated condition. The workings consist of two tunnels several hundred feet in length, several stopes, and a shaft.

The deposit occurs in a band of limestone 20 to 30 feet wide interbedded with schist and cut by quartz diorite. The limestone dips nearly vertically, and is impregnated with garnet, epidote, pyroxene, chalcopyrite, bornite, chalcocite, covellite, and small amounts of an undetermined white metallic mineral. Very little ore was seen in the lower tunnel and the stopes were not accessible. The upper workings showed considerable ore of fairly high grade, but owing to the condition of the tunnel it was impossible to get even a rough idea of the amount present. This deposit is similar to a great many of the same type found in the coast section of British Columbia, and only two or three of which have proved to be of commercial value.

Another deposit similar to this occurs also on Gribbell island and was extensively explored at the same time, but the writer could get no information regarding its location.

An interesting copper deposit occurs on the east side of Kemano river 7 miles from its mouth. This river flows into Gardiner canal about 30 miles above its entrance into Douglas channel. The property was discovered and staked in 1901 by an Englishman named Pocklington, who was later found dead in his cabin with bullet wounds in his head, which were presumably inflicted by himself. In 1914 J. L. Stewart, a well known prospector of Prince Rupert, restaked the claims, which had lapsed, and named them the Tekla group, by which name they are still known. Stewart sold the claims to the present owners, Messrs. M. M. Stephens, H. B. Babbington, and H. Flewin, the last of Port Simpson, and the two first of Prince Rupert. In September, while the writer was examining the shores of Gardiner canal, he fortunately met Mr. Flewin with a number of associates, including Mr. Stewart, who were camped at the mouth of Kemano river waiting for suitable weather to ascend the river and complete the assessment work for the season. The extremely wet weather prevented the writer from visiting the claims, but the following information was obtained from the owners; and from the examination of a number of specimens which were kindly supplied by Mr. Flewin and his partners.

According to Mr. Flewin's description, the deposit is a mineralized zone 100 to 200 feet wide and a smaller ledge 7½ feet wide lying 300 feet to the east and carrying bornite and chalcopyrite.

The specimens from the main ledge consist of quartz and aplite and some altered quartz diorite, in all of which are disseminated small particles of chalcopyrite, molybdenite, and a very small amount of bornite. Specimens from what was thought to be the hanging-wall of this zone represent a very highly altered quartz-bearing rock now

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consisting of quartz, muscovite, sericite, chlorite, and epidote, and strongly coloured by iron oxides. A sample from the 7½-foot quartz ledge consisted of quartz with considerable amounts of bornite and chalcopyrite, forming medium high-grade copper ore.

What is said to be the most promising copper-gold deposit of the district occurs at a high elevation and on both sides of a deep canyon on the river that flows into Kutze inlet, a short branch on the east side of Graham reach, about 5 miles north of Swanson Bay. The property is owned by Messrs. William Shannon, George Martin, and J. B. Mathers of Vancouver. The sum of $150,000 has been spent in developing the property and in constructing a tram-line, which runs from the beach up the river for 3 miles the greater part of the distance to the deposit. It was reported during the season that eastern capitalists were negotiating with the above-mentioned owners for the purchase of the property, but up to the present the sale has not been reported.

The showings are, in spite of the tram-line, at present rather difficult of access and, through lack of a map of the property or a guide, the writer was unable to see them. The geology of the district shows that the deposits lie east of the eastern contact of the large inclusion of schist which outcrops along Fraser and Graham reaches for 21 miles.

MAGNETITE DEPOSIT

A small deposit of very pure magnetite occurs on the northwest shore of Dean channel about halfway between its head and its junction with Labouchere channel. Shipments amounting to 1,200 tons were made from the deposit to a company in Seattle who used it experimentally in an attempt to convert magnetite directly into steel by an electrical process. As these experiments were made some months ago, and as no shipments of magnetite have been made since, it may be assumed that the process was not a success. The deposit occurs only a few hundred feet from the shore and at an elevation of about 200 feet. The magnetite occurs in a dark green chloritic schist which lies between two large dykes or masses of quartz diorite, one of which is about 200 feet wide and the other about 500 feet wide, and situated about 300 feet part. About one-half mile to the northeast a mass of quartz diorite several miles in length outcrops along the shore. The magnetite occurs as large masses of almost pure mineral, which have been uncovered for an horizontal distance of about 200 feet and a vertical distance of 100 feet. The width is quite irregular, varying from a few feet up to 40 feet and averaging about 20 feet. Its unusual purity and very convenient location make it one of the more promising of the numerous small magnetite deposits which occur along the coast mostly to the south of Queen Charlotte sound.

GALENA DEPOSIT

A small but interesting deposit of galena occurs about half a mile from Swanson Bay on the southwest bank of the creek from which the pulp mill derives its water. The deposit is a small, irregular, mineralized zone in micaceous schist. The minerals lie in a faulted zone parallel to the schistosity and striking north 30 degrees west and dipping 65 to 75 degrees northeast.

The mineralized zone consists of quartz stringers and silicified schist containing considerable pyrite and a little galena. Under the microscope the ore was seen to consist of pyrite, pyrrhotite, zinc blende, galena, and chalcopyrite. The iron sulphides were deposited first, then the zinc blende and chalcopyrite, and lastly the galena. No silver minerals were detected. The chief interest in this deposit lies in the fact that it is the only occurrence of galena in the district, and one of the few deposits of galena occurring west of the Pacific system.

THERMAL SPRINGS

Hot springs occur at eight widely separated localities in this district, at most of which there are several springs. Six of these localities were visited by the writer

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and the springs sampled. Owing to the lack of suitable containers the samples were taken in ordinary commercial acid bottles holding about two litres. The samples were analysed by R. T. Elworthy of the Mines Branch, Ottawa, but, because of the smallness of the samples not all the determinations asked for could be made. The results of the analyses are given in the tables (pages 42-49).

The flow of water from each of the springs is not great, but in most cases is sufficient for bathing establishments even on a fairly large scale. At most of the more accessible springs the loggers or fishermen have built small bathing houses, with wooden tubs, which are much used by the men of the district. A large spring in South Bentinck arm has been equipped with enamel bath tubs by the Pacific Mills Paper Company of Ocean Falls, for the use of the employees of the company engaged in logging in that vicinity.

The analyses show that four of the seven springs sampled contain less than 400 parts a million of dissolved salts, which is rather low for hot springs. The three remaining springs contain 1,229, 3,623, and 8,640 parts a million of dissolved salts, the last being comparatively high.

All of the springs but two have sulphate waters and all of these are sodium sulphate except the Dean Channel spring (sample 1) which is a calcium sulphate-calcium bicarbonate spring. The two which are not sulphate springs are the Klekane spring (sample 2) and the Surf Inlet Mine spring (sample 6), both of which are sodium chloride springs and greatly exceed all the others in total salinity. The bicarbonate radicle is prominent in only three springs, the Dean Channel spring and the two Gardiner Canal springs (samples 5 and 7), both of which are sodium sulphate springs. Silica is moderately high in all except the two chloride springs, in which it is very low. Excepting the Dean Channel spring calcium forms less than 10 per cent of the dissolved material. Magnesium is absent from all the sulphate springs except the two in Gardiner canal, and forms about 2 per cent of the salts of the chloride springs. There is no indication of the presence of hydrogen sulphide in any of the springs. There are then three clearly defined types of water in these springs, sodium sulphate, sodium chloride, and calcium sulphate.

All of the springs issue from fissures in the quartz diorite of the Coast Range batholith, except one in Gardiner canal which occurs in a large inclusion of schist. Masses of schist also occur within half a mile of the Dean Channel spring and the Surf Inlet Mine springs, but not within several miles of the other springs.

Springs of the sodium sulphate and calcium sulphate types, although common in sedimentary rocks, are rarely found, as these are, in igneous rocks. Sodium chloride springs are also commonly found in sedimentary rocks, but are equally common in igneous rocks associated with recent volcanic activity. Although recent igneous activity has taken place in this district it is doubtful in most cases if the springs have any genetic connexion with such activity. Most of the springs occur at great distances from any of the recent dykes or tuffs, and no hot springs occur within 24 miles of—and most of them are from 45 to 80 miles distant from—the centre of this vulcanism. Recent dykes were found near the Bishop Cove spring, but this spring differs in no respect from the other sodium sulphate springs. The absence of boron is a further indication that they are not related to the recent vulcanism. Similar springs of both the sodium sulphate and sodium chloride types occur in southeastern Alaska about 400 miles northwest of this district. These occur in similar rocks and their origin has been attributed by Alfred H. Brooks and Gerald A. Warring[1] to the fact that they occur in a region which has been repeatedly subjected to deformation and fissuring, some of which took place during Tertiary time.

The springs here described occur in the same general region of deformation and some of them, such as the Surf Inlet Mine spring and the Dean Channel spring, occur in the vicinity of pronounced faulting. It is probable that these springs owe their heat to the great depths from which they ascend through these fissures.

[1] "Mineral Springs of Alaska," Water Supply Paper 418, U.S. Geol. Surv., 1917.

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This fact, however, makes it all the more difficult to account for the source of the calcium and sodium sulphate and sodium chloride. The rocks through which they pass are rich in both sodium and calcium, but the sulphate and chlorine cannot be accounted for. The fact that those having no chlorine occur right at the seashore scarcely above high tide, whereas those high in chlorine are the farthest inland, that at Surf Inlet being 7 miles from the sea, would strongly indicate that the waters are not contaminated to any extent by sea water.

The therapeutic value of these springs cannot be fully estimated until more complete analyses be made to determine the presence of lithia, barium, strontium, iodine, bromine, etc., and until the radio-activity of the springs has been determined. Though they lack such characteristic ingredients as sulphuretted hydrogen, carbon dioxide gas, and magnesium sulphate, still their compositions are similar to some of the well-known medicinal springs and they may yet prove to have considerable therapeutic value. The inhabitants of the district claim to have received beneficial results from bathing in these springs. Very similar springs in southeastern Alaska have been popular health resorts for many years.

Sulphate waters which precipitate chiefly calcium sulphate on evaporation, such as the Dean Channel spring, are among the most common potable waters on the market.

Sample I

Source. Water from hot spring in Eucott bay, west side of Dean channel, opposite Labouchere channel. Spring 200 feet from shore and about 15 feet above high tide.
Issues from a crevice in the quartz diorite at the foot of a steep cliff.
Temperature too hot for bathing.
Colour—Colourless.
Turbidity—Clear.
Taste—Flat.
Reaction to methyl orange—Alkaline.
Specific gravity at 15° C.—1·0005.
Properties of reaction in per cent—

	Per cent
Primary salinity	28·2
Secondary salinity	49·6
Primary alkalinity	....
Secondary alkalinity	22·2

Analysis

Constituents	Parts per million	Total inorganic matter in solution Per cent	Reacting value Per cent
Carbonic acid (CO_3)	.....	.....	.....
Bicarbonic acid (HCO_3)	33	17·2	11·1
Sulphuric acid (SO_4)	80	41·8	34·4
Chlorine (Cl)	8	4·5	4·5
Sodium (Na)	16	8·3	14·1
Potassium (K)	.....	.....	.....
Calcium (Ca)	35	18·2	35·9
Magnesium (Mg)	trace	.....	.....
Iron oxide and alumina	3	1·5	.....
Silica (SiO_2)	16·9	8·7	.....
Total	191·9	.....	.....
Total solids in solution, residue dried at 110°C	145	.....	.....

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Hypothetical Combination

Constituents		Parts per million	Solids in sol. Per cent
Sodium chloride	($NaCl$)	13	6·8
Potassium chloride	(KCl)	.....	.....
Magnesium chloride	($MgCl_2$)	.....	.....
Sodium sulphate	(Na_2SO_4)	33·5	17·5
Magnesium sulphate	($MgSO_4$)	.....	.....
Calcium sulphate	($CaSO_4$)	81·7	42·6
Sodium carbonate	(Na_2CO_3)	.....	.....
Sodium bicarbonate	($NaHCO_3$)	.....	.....
Magnesium bicarbonate	($Mg(HCO_3)_2$)	.....	.....
Calcium bicarbonate	($Ca(HCO_3)_2$)	43·8	22·8
Ferric oxide and alumina	(Fe_2O_3 and Al_2O_3)	3·0	1·5
Silica	(SiO_2)	16·9	8·7
Total		191·9	100·0

Sample II

Source. Water from hot spring at head of Klekane inlet off Fraser reach, 5 miles north of Butedale cannery. The spring is about 200 yards from the shore and 20 feet above high tide.

Issues from crevice in quartz diorite.
Temperature above 112° Fahrenheit.
Colour—Colourless.
Turbidity—Clear.
Taste—Slightly salty.
Reaction to methyl orange—Alkaline.
Specific gravity at 15° C.—1·0075.

Properties of reaction in per cent—	Per cent
Primary salinity	76·8
Secondary salinity	22·4
Primary alkalinity	....
Secondary alkalinity	0·8

Analysis

Constituents		Parts per million	Total inorganic matter in solution Per cent	Reacting value Per cent
Carbonic acid	(CO_3)	.....	.....	.....
Bicarbonic acid	(HCO_3)	58	0·7	0·33
Sulphuric acid	(SO_4)	717	8·3	5·12
Chlorine	(Cl)	4600	53·3	44·50
Sodium	(Na)	2523	29·2	37·7
Potassium	(K)	82	0·9	0·7
Calcium	(Ca)	385	4·5	6·6
Magnesium	(Mg)	179	2·1	5·0
Iron oxide and alumina		58	0·6	.....
Silica	(SiO_2)	38	0·4	.....
Total		8640	100·0	100·0
Total solids in solution, residue dried at 110° C.		9384		

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Hypothetical Combination

Constituents		Parts per million	Solids in sol. Per cent
Sodium chloride	($NaCl$)	6410	74·3
Potassium chloride	(KCl)	156	1·8
Magnesium chloride	($MgCl_2$)	701	8·1
Sodium sulphate	(Na_2SO_4)	.....	.....
Magnesium sulphate	($MgSO_4$)	.....	.....
Calcium sulphate	($CaSO_4$)	1014	11·7
Sodium carbonate	(Na_2CO_3)	.....	.....
Sodium bicarbonate	($NaHCO_3$)	.....	.....
Magnesium bicarbonate	($Mg(HCO_3)_2$)	.....	.....
Calcium bicarbonate	($Ca(HCO_3)_2$)	76	0·8
Ferric oxide and alumina	(Fe_2O_3 and Al_2O_3)	38	0·4
Silica	(SiO_2)	58	0·6
Calcium chloride	($CaCl_2$)	188	2·2
Total		8641·0	100·0

Sample III

Source. Water from hot spring on shore of Ursula channel 2¾ miles north of Fisherman cove and 15 miles northwest of Butedale cannery. Spring is right at shoreline and 1 foot above high tide.

Issues from crevice 1 inch wide and about 6 feet long in quartz diorite.

Temperature much higher than 112° Fahrenheit.

Colour—Colourless.

Turbidity—Clear.

Taste—No taste.

Reaction to methyl orange—Alkaline.

Specific gravity at 15° C.—1·008.

Properties of reaction in per cent—	Per cent
Primary salinity	75·7
Secondary salinity	16·5
Primary alkalinity	....
Secondary alkalinity	7·8

Analysis

Constituents		Parts per million	Total inorganic matter in solution Per cent	Reacting value Per cent
Carbonic acid	(CO_3)	9·9	2·5	3·55
Bicarbonic acid	(HCO_3)	2·0	0·5	0·35
Sulphuric acid	(SO_4)	173·6	44·1	38·85
Chlorine	(Cl)	24·0	6·1	7·24
Sodium	(Na)	81·0	20·5	37·83
Potassium	(K)	.....	.....	.....
Calcium	(Ca)	22·2	5·6	11·93
Magnesium	(Mg)	0·3	.....	0·22
Iron oxide and alumina		22·7	5·7	.....
Silica	(SiO_2)	58·8	14·9	.....
Total		394·5	100·0	100·00
Total solids in solution, residue dried at 110° C.		370		

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Hypothetical Combination

Constituents		Parts per million	Solids in sol. Per cent
Sodium chloride	($NaCl$)	39·4	10·0
Potassium chloride	(KCl)	.....	.....
Magnesium chloride	($MgCl_2$)	.....	.....
Sodium sulphate	(Na_2SO_4)	204·0	51·8
Magnesium sulphate	($MgSO_4$)	1·2	0·3
Calcium sulphate	($CaSO_4$)	50·0	12·7
Sodium carbonate	(Na_2CO_3)	.....	.....
Sodium bicarbonate	($NaHCO_3$)	.....	.....
Magnesium bicarbonate	($Mg(HCO_3)_2$)	.....	.....
Calcium bicarbonate	($Ca(HCO_3)_2$)	2·6	0·6
Ferric oxide and alumina	(Fe_2O_3 and Al_2O_3)	22·7	5·7
Silica	(SiO_2)	58·8	14·9
Calcium carbonate		16·0	4·0
Total		394·7	100·0

Sample IV

Source. Water from west side of Bishops cove, Ursula channel, 24 miles northeast of Butedale cannery. The spring is 60 feet from the shore and 10 feet above high tide.

It issues from a crevice in quartz diorite.

Temperature much higher than 112° Fahrenheit.

Colour—Colourless.

Turbidity—Clear.

Taste—Tasteless.

Reaction to methyl orange—Alkaline.

Specific gravity at 15° C.—1·0012.

Properties of reaction in per cent—	Per cent
Primary salinity	81·64
Secondary salinity	12·84
Primary alkalinity	....
Secondary alkalinity	5·52

Analysis

Constituents		Parts per million	Total inorganic matter in solution Per cent	Reacting value Per cent
Carbonic acid	(CO_2)	6·6	1·7	2·25
Bicarbonic acid	(HCO_3)	3·3	0·8	0·51
Sulphuric acid	(SO_4)	178·5	44·6	37·95
Chlorine	(Cl)	32·0	8·0	9·29
Sodium	(Na)	92·0	23·0	40·82
Potassium	(K)	.....	.....	.....
Calcium	(Ca)	17·6	4·4	8·98
Magnesium	(Mg)	0·3	.....	0·20
Iron oxide and alumina		5·0	1·2	.....
Silica	(SiO_2)	64·7	16·2	.....
Total		400·0	100·0	100·0
Total solids in solution, residue dried at 110° C.		408		

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Hypothetical Combination

Constituents		Parts per million	Solids in sol. Per cent
Sodium chloride	($NaCl$)	52·2	13·0
Potassium chloride	(KCl)	.....	.....
Magnesium chloride	($MgCl_2$)	.....	.....
Sodium sulphate	(Na_2SO_4)	219·5	54·9
Magnesium sulphate	($MgSO_4$)	1·2	0·3
Calcium sulphate	($CaSO_4$)	41·5	10·4
Sodium carbonate	(Na_2CO_3)	.....	.....
Sodium bicarbonate	($NaHCO_3$)	.....	.....
Magnesium bicarbonate	($Mg(HCO_3)_2$)	.....	.....
Calcium bicarbonate	($Ca(HCO_3)_2$)	4·1	1·1
Ferric oxide and alumina	(Fe_2O_3 and Al_2O_3)	5·0	1·2
Silica	(SiO_2)	64·7	16·2
Calcium carbonate		11·0	2·8
Total		399·7	100·0

Sample V

Source. Water from hot spring on Gardiner canal, between Shearwater and Low points and about 12 miles from the entrance of the canal into Desolation channel.

Spring is at water's edge on a small vertical cliff about 2 feet above high tide.

It issues from a crevice about 2 inches wide and several feet long in chloritic schist.

Temperature much higher than 112° Fahrenheit.

Colour—Colourless.

Turbidity—Clear.

Taste—Tasteless.

Reaction to methyl orange—Alkaline.

Specific gravity at 15° C.—1·002.

Properties of reaction in per cent—	Per cent
Primary salinity	75·88
Secondary salinity	6·76
Primary alkalinity	....
Secondary alkalinity	17·36

Analysis

Constituents		Parts per million	Total inorganic matter in solution Per cent	Reacting value Per cent
Carbonic acid	(CO_3)	.....	.....	.....
Bicarbonic acid	(HCO_3)	167	13·6	8·68
Sulphuric acid	(SO_4)	546	44·4	36·07
Chlorine	(Cl)	60	4·9	5·25
Sodium	(Na)	258·5	21·1	35·57
Potassium	(K)	29·3	2·4	2·37
Calcium	(Ca)	67·4	5·5	10·66
Magnesium	(Mg)	5·4	0·4	1·39
Iron oxide and alumina		5·0	0·4	.....
Silica	(SiO_2)	90·4	7·3	.....
Total		1229	100·0	100·00
Total solids in solution, residue dried at 110° C.		1132	.....	.....

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Hypothetical Combination

Constituents		Parts per million	Solids in sol. Per cent
Sodium chloride	($NaCl$)	55·0	4·4
Potassium chloride	(KCl)	55·4	4·5
Magnesium chloride	($MgCl_2$)	.....	.....
Sodium sulphate	(Na_2SO_4)	732·0	59·6
Magnesium sulphate	($MgSO_4$)	26·4	2·1
Calcium sulphate	($CaSO_4$)	42·8	3·5
Sodium carbonate	(Na_2CO_3)	.....	.....
Sodium bicarbonate	($NaHCO_3$)	.....	.....
Magnesium bicarbonate	($Mg(HCO_3)_2$)	.....	.....
Calcium bicarbonate	($Ca(HCO_3)_2$)	221·9	18·0
Ferric oxide and alumina	(Fe_2O_3 and Al_2O_3)	5·0	0·4
Silica	(SiO_2)	90·4	7·4
Total		1229·0	100·0

Sample VI

Source. Water from the 900-foot level on Surf Inlet mine, Princess Royal island. This is 7 miles from the nearest salt water at Surf inlet, and 200 feet above sea-level.

The water issues from a crevice in quartz diorite.

The temperature is slightly below atmospheric temperature in the mine.

Colour—Colourless.

Turbidity—Clear.

Taste—Slightly salty.

Reaction to methyl orange—Alkaline.

Specific gravity at 15° C.—1·0034.

Properties of reaction in per cent—	Per cent
Primary salinity	62·4
Secondary salinity	36·6
Primary alkalinity	....
Secondary alkalinity	1·0

Analysis

Constituents		Parts per million	Total inorganic matter in solution Per cent	Reacting value Per cent
Carbonic acid	(CO_2)	.....	.....	.....
Bicarbonic acid	(HCO_3)	33	0·9	0·5
Sulphuric acid	(SO_4)	553	15·3	9·6
Chlorine	(Cl)	1696	46·9	39·9
Sodium	(Na)	816	22·5	29·6
Potassium	(K)	75	2·1	1·6
Calcium	(Ca)	318	8·7	13·3
Magnesium	(Mg)	78·5	2·2	5·5
Iron oxide and alumina		5·0	0·1	.....
Silica	(SiO_2)	49	1·3	.....
Total		3623·5	100·0	100·0
Total solids in solution, residue dried at 110° C.		3971	.....	.....

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Hypothetical Combination

Constituents		Parts per million	Solids in sol. Per cent
Sodium chloride	($NaCl$)	2075	57·3
Potassium chloride	(KCl)	143	3·9
Magnesium chloride	($MgCl_2$)	311	8·6
Sodium sulphate	(Na_2SO_4)	.....	.....
Magnesium sulphate	($MgSO_4$)	.....	.....
Calcium sulphate	($CaSO_4$)	784	21·6
Sodium carbonate	(Na_2CO_3)	.....	.....
Sodium bicarbonate	($NaHCO_3$)	.....	.....
Magnesium bicarbonate	($Mg(HCO_3)_2$)	.....	.....
Calcium bicarbonate	($Ca(HCO_3)_2$)	43·7	1·3
Ferric oxide and alumina	(Fe_2O_3 and Al_2O_3)	5·0	0·1
Silica	(SiO_2)	49·0	1·3
Calcium chloride		213	5·9
Total		3623·7	100·0

Sample VII

Source. Water from a hot spring on the southeast side of Brim river which flows into Gardiner canal 20 miles from its entrance into Desolation channel.

The spring was found about 200 yards above the mouth of the river, and on the bank of the river. The sample was probably diluted with the river water.

The temperature was about 100° Fahrenheit, which is lower than that of any of the other hot springs.

Colour—Colourless.

Turbidity—Clear.

Taste—Tasteless.

Reaction to methyl orange—Alkaline.

Specific gravity at 15° C.—1·0005.

Properties of reaction in per cent—	Per cent
Primary salinity	50·8
Secondary salinity	31·8
Primary alkalinity	....
Secondary alkalinity	17·4

Analysis

Constituents		Parts per million	Total inorganic matter in solution Per cent	Reacting value Per cent
Carbonic acid	(CO_3)	.....	.....	.....
Bicarbonic acid	(HCO_3)	40·0	14·2	8·7
Sulphuric acid	(SO_4)	78	27·9	21·7
Chlorine	(Cl)	52·0	18·5	19·6
Sodium	(Na)	43·4	15·6	25·4
Potassium	(K)	.....	.....	.....
Calcium	(Ca)	16·6	5·9	11·1
Magnesium	(Mg)	12·2	4·3	13·5
Iron oxide and alumina		3·0	1·0	.....
Silica	(SiO_2)	35·5	12·6	.....
Total		280·7	100·0	100·0
Total solids in solution, residue dried at 110° C.		273		

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Hypothetical Combination

Constituents		Parts per million	Solids in sol. Per cent
Sodium chloride	($NaCl$)	85·2	30·4
Potassium chloride	(KCl)	.....	.....
Magnesium chloride	($MgCl_2$)	.....	.....
Sodium sulphate	(Na_2SO_4)	30·5	10·9
Magnesium sulphate	($MgSO_4$)	60·7	21·6
Calcium sulphate	($CaSO_4$)	12·2	4·3
Sodium carbonate	(Na_2CO_3)	.....	.....
Sodium bicarbonate	($NaHCO_3$)	.....	.....
Magnesium bicarbonate	($Mg(HCO_3)_2$)	.....	.....
Calcium bicarbonate	($Ca(HCO_3)_2$)	53·6	19·1
Ferric oxide and alumina	(Fe_2O_3 and Al_2O_3)	3·0	1·0
Silica	(SiO_2)	35·5	12·6
Total		280·7	100·0

Sample VIII

Source. Salts deposited by the hot spring on Dean channel from which sample I was taken.

The sample was taken from the edge of a large boulder which projected over the top of the spring and was about 3 feet above the surface of the water. The salts were deposited by the vapours from the hot water.

	Per cent
CaO	29·50
MgO	0·44
Fe_2O_3 and Al_2O_3	0·62
Na_2O	0·26
SO_3	42·00
CO_2	Very small quantity, undetermined
H_2O	25·00
SiO_2	2·00
Boron	trace
	99·82

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COPPER DEPOSITS ON LASQUETI ISLAND, BRITISH COLUMBIA

By J. D. MacKenzie

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INTRODUCTION

Lasqueti island is situated between Vancouver island and Texada island, in the strait of Georgia. It is separated from the south end of Texada island by Sabine channel. The island is 10 miles long and averages between 2½ and 3 miles wide, with its longer axis lying northwest and southeast. It has a much indented shoreline, which is for the most part steep and rocky, with shingle beaches at the heads of the narrow bays. The surface is characterized by irregular, rounded rocky hills, the highest of which, mount Tremeton, attains an altitude of 1,056 feet. Bare rock forms a large proportion of the surface, but some of the valleys near sea-level are filled with till or alluvium sufficient to form soil suitable for cultivation.

There are small settlements at Tucker bay on the east coast, and at False bay at the northwest end of the island, where there is also a salmon cannery. A coasting steamer calls once a week at Tucker bay, and a regular service is maintained by gasoline launch between that bay and Pender harbour on the mainland.

The field work on which this report is based occupied ten days in July, 1921. The primary object in visiting the island was to study the basal Cretaceous rocks which occur there in several places, but the greater part of the ten days was spent examining and mapping the area here reported on. The general map (Figure 9) of Lasqueti island accompanying this report is a revision of the one published by Dawson in 1886; the map of the Venus and St. Joseph groups was made during the present examination.

Previous investigations on Lasqueti island were made by Richardson[1] and by Dawson[2]. Dawson gives a full description of the Cretaceous sediments as well as of the pre-Cretaceous volcanic rocks. He also mentions the "granite" of False bay, but did not follow its extension across the island to Barnes cove.

In 1920 the mineral claims were described by W. M. Brewer.[3]

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[1] Richardson, James, Geol. Surv., Can., Rept. of Prog., 1876-77, pp. 168-169.
[2] Dawson, G. M., Geol. Surv., Can., Ann. Rept., vol. II, pt. B, 1886, pp. 41-44.
[3] Brewer, W. M., Ann. Rept., Min. of Mines, B.C., 1920, p. 213.

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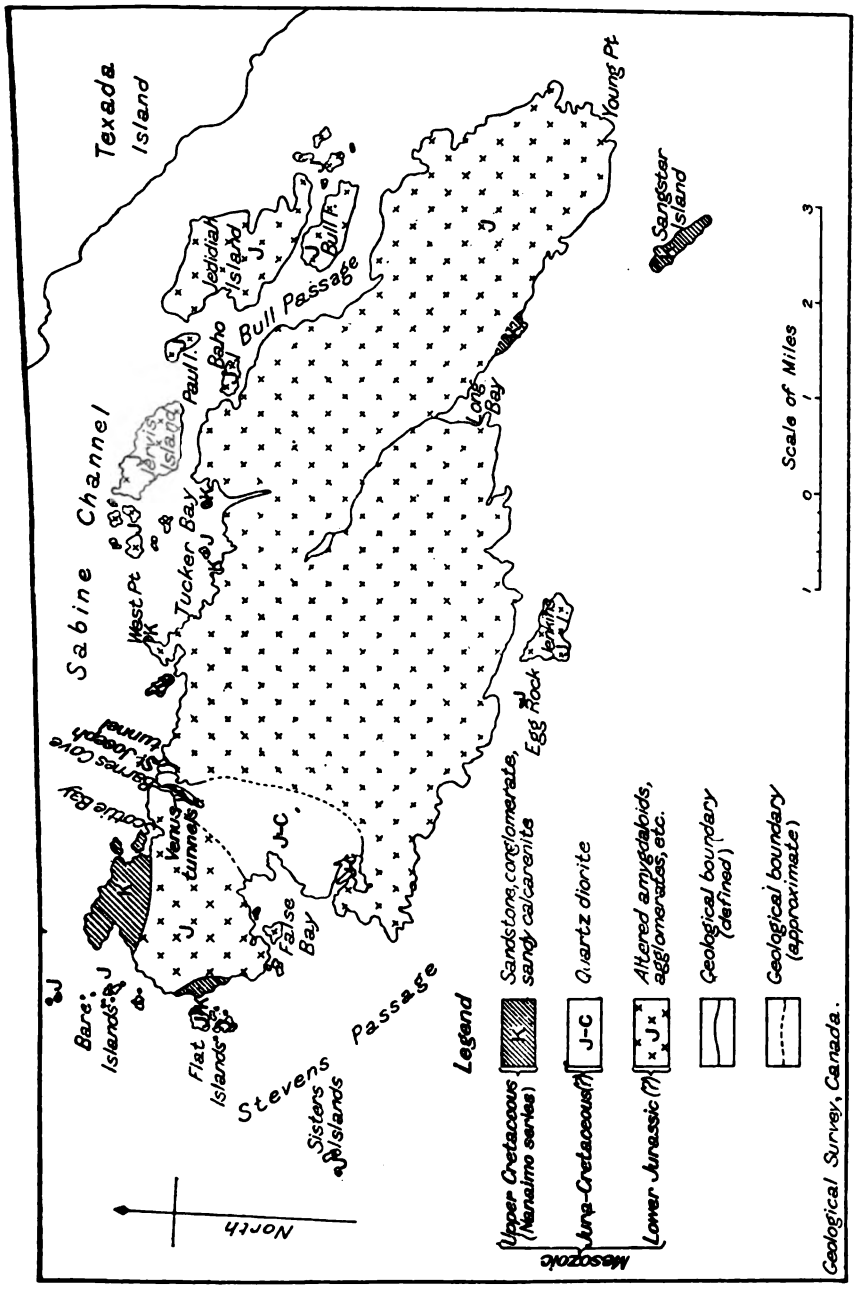

Figure 9. Geological map of Lasqueti island, strait of Georgia, B.C.

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GENERAL GEOLOGY

Table of Formations

Period	Formation	Lithology
Pleistocene and Recent	Alluvium and Glacial deposits	Stratified sand, till, swamp deposits
	Unconformity	
Upper Cretaceous	Nanaimo series	Conglomerate, sandstone, sandy calcarenite
	Unconformity	
Jura-Cretaceous (?)	Dykes	Quartz diorite porphyries (?)
	Intrusive contact	
	Satellitic rocks of the Coast batholith	Quartz diorite
	Intrusive contact	
Lower Jurassic	Texada formation	Altered amygdaloids and agglomerates

Except for the small area underlain by quartz diorite between False bay and Barnes cove, and that occupied by Cretaceous rocks, the whole surface of Lasqueti island is occupied by altered volcanic rocks to which the name Texada formation is applied.

These rocks are amygdaloids, agglomerates, and tuffs and with them are dense compact rocks which may have been flows or sills. Dawson's general description is quoted here:

"The island is composed, for the most part, of altered volcanic rocks, which are probably a repetition of those met with on the adjacent portion of the shore of Texada island, Sabine channel, occupying an intervening synclinal. The strikes of the beds, on the sides of the channel, diverge to the northwestward, coinciding approximately in direction with the opposite shorelines. The northern portion of the island is chiefly composed of amygdaloids, while the southern is formed principally of agglomerates, which have, however, in many places, been so much altered as to require very close examination to detect their true character. Some compact trappean beds occur in association with the agglomerates, which have evidently been lava-flows; one of these, near point Young, shows a fairly well-marked columnar structure, and another, three-quarters of a mile north from the southeast point, on Bull passage, affords an excellent example of the 'ropy' structure above alluded to. This peculiar structure was not infrequently observed in other places in connexion with the altered volcanic rocks and is pretty evidently that of the surface of a lava-flow, resembling those found on Vesuvius and other recent volcanoes. The flow of the viscous or partly consolidated mass, has produced a confused aggregate of knotted, rounded, and irregularly cylindrical forms of an involved character, and without distinct interspaces. The structure is not merely superficial, but affects a considerable mass of material, which in this instance is now a bluish feldspathic rock, not evidently amygdaloidal. The lithological characters of the other rocks of the altered volcanic series on Lasqueti are so similar to those of the rocks of Texada as not to require special description."[1]

Two typical specimens of these rocks were examined in thin section, and found to consist essentially of andesine feldspar in lath-like and tabular crystals, and a pale brown hornblende. An opaque mineral, probably magnetite, is present in considerable amounts as an accessory. This mineral composition determined the rocks to be andesites. They are comparatively fresh rocks, and their slight alteration is surprising.

[1] Dawson, G. M., Geol. Surv., Can., Ann. Rept., vol. II, pt. B, p. 41.

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The structure of these volcanic rocks is not evident, but it is fairly apparent that they form part of an effusive and pyroclastic bedded formation, striking northwest (parallel to the longer direction of the island) and dipping from 20 to 40 degrees to the northeast. This interpretation agrees with the views of Dawson as quoted above.

A feature of these volcanics is the vertical crushed zones contained in them. There are many such zones along the shore from Barnes cove to Scottie bay; they are from 1 inch to 2 feet wide and strike from 10 degrees west of north to 25 degrees east of north. These zones have apparently had a considerable localizing influence on the mineralization presently to be described. On the basis of Dawson's description, and their lithological composition, these altered volcanics are correlated with the Texada formation of Texada island. McConnell, who named this formation, states that it "probably belongs to the same volcanic period as the Vancouver volcanics of Vancouver island,"[1] which are of Lower Jurassic and Triassic age.[2]

SATELLITIC ROCKS OF THE COAST BATHOLITH

Under this name are included plutonic rocks which underlie the area between False bay on the south of the island and Barnes cove on the north.

The rock at False bay is light grey, medium to fine, even grained, with a pinkish cast on the weathered surface. Quartz is plainly visible in the hand specimen. In thin section the essential minerals are andesine (plagioclase feldspar) and quartz; with subordinate hornblende, biotite, and augite, and accessory apatite and magnetite. The constituents, except the quartz, are all sharply crystallized and the texture is even. The rock is fresh; the andesine is only slightly altered, and the biotite shows only incipient alteration to chlorite.

In the vicinity of Barnes cove the most common rock is grey, fresh-looking, medium even-grained quartz diorite. In thin section it is generally similar to the rock just described, but there is noticeably less quartz and rather more ferromagnesian minerals. This agrees with the difference in appearance in the hand specimen; the Barnes Cove rock being several shades darker than the False Bay variety, and with inconspicuous quartz. The hornblende forms rims surrounding the augite, which is not abundant. The quartz diorite is usually fresh looking and very little alteration can be detected in thin section, but in the shear zones the rock is greatly altered, and its identity is often doubtful in the field. This sheared, altered variety appears under the microscope as a mixture of altered feldspar, calcite, quartz, and chlorite, with the usual accessory minerals, and in addition titanite, which was not found in the slides of the fresher rocks. It is as a replacement of this altered and sheared quartz diorite that the ore-shoots occur.

Near the contact with the volcanics variations in grain are common, but the quartz diorite is not chilled. In some places on the Venus group concentrations of bladed crystals of hornblende up to 2 inches long occur in irregular schlieren in the quartz diorite. At the contact on the shore west of the St. Joseph tunnel the intrusive is exceptionally rich in hornblende, which forms 80 per cent of the rock, forming equant crystals up to $\frac{1}{16}$ inch across. This rock is tightly sealed against the volcanics, without any sign of chilling. Here, also, the contact relations indicate intrusion of the quartz diorite into rocks which were sufficiently hot not appreciably to chill the intrusive. The dykes and apophyses extending from the quartz diorite into the volcanics are frequently fine-grained, pinkish and reddish aplitic rocks. These aplites also occur in dykes or veins of varying shape and size cutting the quartz diorite itself.

DYKES

Besides the dykes and apophyses clearly related to the quartz diorite that cut the volcanics, certain others occur which have not been observed intruding the quartz

[1] McConnell, R. G., Geol. Surv., Can., Mem. 58, 1914, p. 26.
[2] Clapp, C. H., Geol. Surv., Can., Mem. 36, 1913, p. 28.
Clapp, C. H., Geol. Surv., Can., Mem. 96, 1917, p. 123.

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diorite. These are dark grey, tough, hard porphyries, with yellowish and greyish white phenocrysts of plagioclase up to ⅛ inch across in a dense matrix in which smaller hornblende phenocrysts also occur. They are probably quartz diorite porphyries.

Near the St. Joseph tunnel one of these dykes contains sparingly disseminated fine-grained pyrite, and along one contact is a crushed zone 6 to 8 inches thick, containing lenticles of pyrite and chalcopyrite 12 inches long by ½ inch thick.

NANAIMO SERIES

Conglomerate, sandstone, and the fragmental type of limestone known as calcarenite, of Upper Cretaceous age, and belonging to the Nanaimo series, outcrop at several localities in such a way as to suggest that the rocks are parts of a once continuous fringe that formerly ran almost around the island. As they were formed after, and have no connexion with the copper deposits they will not be further described here. A description of them is given by Dawson.[1]

ECONOMIC GEOLOGY

COPPER DEPOSITS

Venus Group

The Venus group consists of nine mineral claims and a fraction, extending southerly from Barnes cove across the island. The principal workings are on the Mars claim, which almost surrounds Barnes cove. At the head of the cove two adits have been driven, the lower one at the shore and 5 feet above high-tide line, the upper one 16 feet directly above. The length of the upper tunnel is 80 feet; that of the lower 140 feet. Part of the intervening ground has been stoped, and a winze was extended from the lower tunnel to a depth at the time the property was examined of 70 feet. Besides these underground workings, numerous surface pits, trenches, and strippings have been made.

Only vague surface indications were evident on the Mars claim, but the slight mineralization at the St. Joseph mine and at the mouth of Barnes cove induced some prospectors to do surface stripping at the head of the cove. This work disclosed a seam of oxidized minerals no wider than a knife blade, on which a pit was sunk, disclosing a considerable body of chalcopyrite. The accompanying plan (Figure 10) of the Venus and St. Joseph groups illustrates the surface geology. A tongue of diorite, the most northerly extension of the mass outcropping at False bay, intrudes the metamorphosed volcanics with very irregular contacts. Bifurcating this tongue is a long, narrow strip of the invaded rocks which is thought to represent a roof pendant. Numerous inclusions of the volcanics are found in the diorite, some of which are large enough to be shown on the plan.

It will be observed that the deposit on the Mars claim lies in the intrusive, which at this place is a dark grey, fresh-looking, medium to fine, even-grained rock, composed of about equal amounts of plagioclase and hornblende. It shows minor variations in texture, and is cut by a few narrow aplitic veins.

At the place where the adits have been driven this is crushed and slickensided in a nearly vertical zone striking north 25 degrees east. The width of the zone varies from 4 inches to several feet, and the intensity of crushing is also variable. In some places the rock is so slickensided, crushed, and chloritized that its recognition is a matter of some difficulty. Two hundred feet from the shore at the Venus adit a fault striking east and west offsets the tongue of volcanics for a distance of 45 feet measured horizontally along the fault plane. Further than this the relative movement of the two sides of the fault is not known. In this crushed zone in the diorite

[1] Dawson, G. M., Geol. Surv., Can., Ann. Rept., vol. II, pt. B, 1886, pp. 41-44.

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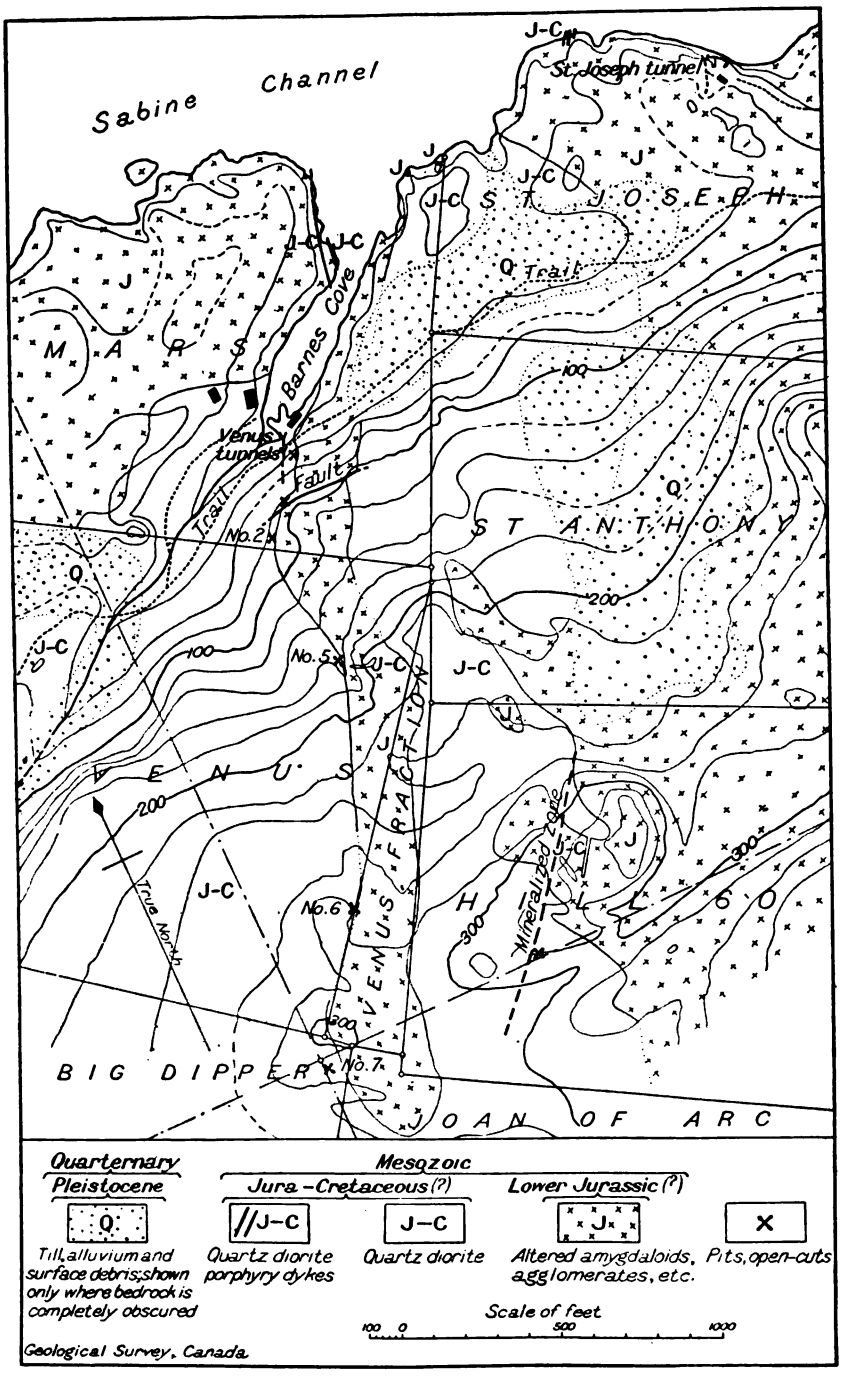

Figure 10. Plan of Venus and St. Joseph groups of mining claims, Lasqueti island, B.C.

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occurs the principal mineralization. This is a shoot of nearly solid chalcopyrite with some pyrite, the greatest thickness of which is 4 feet; in some places now stoped this was solid chalcopyrite, but generally the shoot contained strips of crushed diorite. The stope length of the shoot in the lower tunnel is about 80 feet; as the lower part has not yet been extracted its pitch length or direction is not known.

In the less crushed portion of the zone the chalcopyrite occurs in thin lenses which appear to have been caused partly by filling and partly by replacement. In the more crushed zones the chalcopyrite forms a larger proportion of the total mass, surrounding various sized fragments of slickensided and chloritized quartz diorite and in these zones the principal mode of introduction of the ore is apparently replacement of the crushed rock. A polished surface of typical ore, for the preparation and examination of which the writer is indebted to Mr. George Hanson, corroborates the ideas concerning the formation of the ore by replacement which had been inferred from the field relations and hand specimens. By means of this polished specimen, small, disjointed grains of magnetite were detected in the ore, which explains the faintly magnetic property of some specimens. A mineral thought to be sphalerite also occurs sparingly in small grains.

Up to December, 1921, 196 tons of ore had been shipped to the Tacoma smelter from this deposit, the returns from which are stated to have averaged:

Copper	12·82 per cent
Gold	0·63 oz. per ton
Silver	3·27 ozs. per ton

Though this ore was hand-picked, much of it was shipped just as taken from the mine. A sample that was mostly chalcopyrite is said to have given the following results:

Copper	31·65 per cent
Gold	0·08 oz. per ton
Silver	4·32 ozs. per ton

A sample that was largely pyrite is said to have contained:

Copper	5·50 per cent
Gold	1·16 ozs. per ton
Silver	8·84 ozs. per ton

Along the western contact of the narrow strip of volcanics on the Venus and Venus Fraction claims, a certain amount of mineralization occurs in several pits and trenches. Wherever this mineralization, which consists of disseminated pyrite with small amounts of chalcopyrite, has been found the quartz diorite is crushed and sheared, and the pyrite and chalcopyrite are confined to the sheared parts.

On Hill 60 mineral claim there is a deposit remarkable for its straightness and continuity, to which for lack of a better term the name "mineralized zone" has been applied. This zone is usually from 2 to 4 feet wide and can be traced continuously for 900 feet by means of a depression down to 2 feet deep which it forms on the surface. This depression is marked by the difference between the amount of vegetation growing in it, and that on the adjoining rocks. All along the depression the growth of sallal is noticeably more luxuriant than elsewhere in the vicinity. Its course is also marked by a hedge of small jackpines which are doomed to early decease if one may judge from the *chevaux-de-frise* of their dead predecessors lying along the depression, none of which attained a height of more than 10 feet. The broken material comprising the zone lends itself readily to the soil-forming processes of disintegration and decay. Once a depression was initiated the concentration of moisture in it accelerated the process, at the same time providing in itself an agent favourable to the growth of vegetation.

This mineralized zone crosses quartz diorite and volcanic alike, and is, therefore, a post intrusion feature. No sign of offsetting could be detected where it intersects any of the quartz diorite-volcanic contacts, and it must be a shear or crush zone

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rather than a fault. Two pits have been sunk on it where the zone is in quartz diorite. In the pit at the northeastern end the shearing is 40 degrees east of north, and dips 83 to 85 degrees southeast. A section across the zone from northeast to southwest at this point is as follows:

	Thickness Ft.	In.
The hanging-wall is broken but not greatly sheared.		
Loose sugary pyrite; decomposed to gossan for 6 feet from surface	up to 6	
Greatly crushed quartz diorite		0·5
Massive quartz diorite much iron stained and with disseminated pyrite		4
Sheared quartz diorite with malachite stains		5
Vein of pyrite and chalcopyrite		0·5 to 1
Cracked quartz diorite	3	
Oxidized pyrite and quartz		1
Cracked quartz diorite	2	4
Quartz stringer		0·25
Cracked quartz diorite	1	8
Pyrite and quartz		0·25
	7 ft. 11·5 ins. to 8 ft. 6 in.	

The foot-wall is cracked quartz diorite with paper-thin quartz stringers. A sample of picked material from this pit taken by W. M. Brewer,[1] contained: copper, 14·4 per cent; gold, 0·38 ounce per ton; silver, 1·8 ounces per ton. Northeast of this pit the rocks for several hundred feet are obscured by alluvium and vegetation and the extension of the mineralized zone in that direction cannot be traced. At a distance of 650 feet along the zone from the pit just described another open-cut in the quartz diorite affords the following section of the zone.

The strike of the shearing here is 45 degrees east of north, and the dip 85 degrees northwest, the opposite direction from the dip at the first pit.

	Inches
The hanging-wall is strongly sheared.	
Soft chlorite gouge	4
Loose, sugary pyrite	4
Very soft, clayey gouge	1·5
Incoherent pyrite	0·75
Sheared quartz diorite	2
	12·25

The foot-wall is cracked quartz diorite.

The southwestward extension of this zone, like the northeastward, is concealed by vegetation and alluvium. Mr. Henry Lee, Managing Director of the Lasqueti Island Mining Company that is developing the property, makes the interesting suggestion that there may be a genetic connexion between this mineralized zone and the crushed zone on the St. Joseph claim. The strike of the zone just described, if produced, meets the crushed zone at the St. Joseph tunnel, but the rocks in the intervening distance of 2,000 feet are concealed.

St. Joseph Group

The St. Joseph group, adjoining the Venus group on the east, consists of three claims, two of which are shown on the accompanying plan (Figure 10). The workings consist of an adit just above high-water mark, with a length of 116 feet; an inclined shaft from the surface intersects the adit and is said to extend to a depth of 100 feet, from which point a level parallel to the adit extends for an unknown distance. These workings were made previous to 1908, and since that year the property has not been operated. This deposit lies in a crushed zone in the volcanics which are here more than ordinarily massive, as if the movements in the vicinity had all been localized in one place. The crushed zone is from 2 to 4 feet wide, strikes 30 degrees east of north, and dips 62 degrees northwest. The mineralization

[1] Brewer, W. M., Ann. Rept. Min. of Mines, B.C., 1920, p. 213.

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consists of irregular patches and small shoots of pyrite and chalcopyrite apparently occurring as replacements in the crushed volcanics. There is no indication of any of these shoots having been as large or as rich as the one at the Venus mine. On the steep shore, 80 feet west of the portal of St. Joseph adit, a vertical dyke, probably a quartz diorite porphyry, 10 feet thick, strikes north 30 degrees east. This dyke cuts massive volcanics and along its southeastern contact lies a mineralized streak in a crushed zone 6 to 8 inches thick. This zone contains lenticles of pyrite 12 inches long by ½ inch thick, together with some chalcopyrite and malachite stains. The dyke itself contains some sparingly disseminated pyrite, and it is possible that it has caused the mineralization alongside of it. It is possible, too, that the mineralization of the St. Joseph tunnel is connected with this dyke.

A pile of hand-picked mineralized rock lying at the entrance of the adit was sampled by W. M. Brewer in 1920, and the result of the assay gave:

Copper	11·4 per cent
Gold	0·82 oz. per ton
Silver	2·2 ozs. per ton[1]

Origin

The mineralization and mode of occurrence leave no doubt that both of these occurrences are instances of primary deposition. The location of the Venus deposit near the end of a tongue of quartz diorite projecting into the invaded rock, and its intimate association with shearing in the quartz diorite, lead to the conclusion that the mineralization was caused by some of the later magmatic emanations which were evolved from deeper-seated parts of the quartz diorite mass after the marginal zones had solidified sufficiently to be sheared and crushed. A similar origin can be assigned to the mineralized zone on the Hill 60 claim.

There are two possible modes of origin for the St. Joseph deposit. It, too, may be connected with the quartz diorite, in which case its relative leanness may be due to the greater distance of travel of the metallic minerals, and their localization in the volcanics rather than in the intrusive rock. On the other hand, it may be genetically connected with the porphyry dyke described above.

[1] Brewer, W. M., Ann. Rept., Min. of Mines, B.C., 1920, p. 213.

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PLACER MINING IN BARKERVILLE AREA, BRITISH COLUMBIA

By W. A. Johnston

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INTRODUCTION

Placer mining has been carried on intermittently in Barkerville area ever since the discovery, over sixty years ago, of the gold-bearing creeks—Antler, Williams, Lightning, and several others—which have rendered the district famous. In the early days of mining in the district, the gold was, for the most part, recovered by drifting, and at a later period by hydraulicking; and some of the hydraulic mines have been in operation nearly every year for the past forty years. In recent years attempts have been made to interest capital in the possibilities of gold-dredging, a phase of mining which as yet has not been attempted in the Barkerville area, although it has been successfully carried on in many other placer regions.

Parts of Cariboo district were examined geologically by G. M. Dawson in 1876 and 1894. The results of his work and summaries of the history of placer mining in the region are given in the report of Progress of the Geological Survey, Canada, 1876-77; in the Annual Report for 1887-88, part II, and in the Summary Report, 1894. Cariboo mining district was topographically and geologically mapped in 1885 and 1886 by Amos Bowman, assisted by James McEvoy. The first part of Bowman's report, dealing chiefly with the general geology and the possibilities of lode mining in the district, was published in the Annual Report of the Geological Survey, Canada, 1887-88. The second part, in which it was intended that detailed descriptions of the principal auriferous creeks should be given, was not published. A number of detailed maps of the creeks were prepared by Mr. Bowman, but in June, 1894, he died without having written any descriptive matter to accompany these maps. The maps, however, were published in 1895 by the Geological Survey and were accompanied by an explanatory note by G. M. Dawson.

In 1918 B. R. MacKay, of the Geological Survey, began an investigation of the Cariboo gold region and continued his work during parts of that and the succeeding year. The results of part of his work are contained in the Summary Reports of the Geological Survey for those years. In 1920, a topographic map of the Barkerville area, embracing 210 square miles, was made by D. A. Nichols of the Topographical Division, Geological Survey. The map will be published on the scale of 1 mile to the inch, with a contour interval of 100 feet.

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Much valuable information regarding mining operations in the district is given in the reports of the Minister of Mines of British Columbia, which have been issued annually since 1874. The report for the year 1902 is of special interest, as it contains a comprehensive description by Wm. Fleet Robertson, Provincial Mineralogist, of the placer deposits and the mining operations then in progress. In the report for 1914, the mining operations of the district were described by J. D. Galloway, Assistant Provincial Mineralogist, and a report is now submitted annually by Mr. Galloway as resident engineer of the district. In other years the general progress of, and information about the district have been given by the gold commissioner.

The history of mining in the district prior to 1878 is given in considerable detail by Bancroft in his "History of British Columbia" published in 1887, and also by F. W. Howay and E. O. S. Scholefield in "British Columbia From the Earliest Days to the Present," published in 1914. Interesting data on the subject are to be found in numerous other publications and manuscripts, including the early reports of the gold commissioners, which are available for reference in the excellent Parliamentary library at Victoria, British Columbia. A few rare volumes and manuscripts on Cariboo are available for reference in the Public Archives at Ottawa, also. These old reports, as well as the later reports and Bowman's maps, are of interest and importance because they furnish the main evidence as to which creeks were thoroughly tested in the early days of mining, a question which because of the peculiar condition existing in Cariboo—the presence of glacial drift overlying the gold-bearing gravels—has arisen many times in the past, and will doubtless arise in the future.

Two papers by J. B. Tyrrell, dealing with the geology and placer mines of Cariboo, have been published recently. One of these, entitled "Was There a Cordilleran Glacier in British Columbia?" appeared in the Journal of Geology, vol. 27, 1919, and the other, "Notes on the Placer Mines of Cariboo, British Columbia," was published in Economic Geology, vol. 14, 1919.[1]

The writer spent two months in 1921 in an examination of the placer deposits of Barkerville area and other parts of Cariboo district, continuing the work of B. R. MacKay who resigned from the Geological Survey in 1920. Attention was directed mainly to Williams, Antler, and Grouse creeks, and detailed maps were made of parts of these. No attempt is here made to give a general account of the possibilities of placer mining in the area, for in the short time devoted to its study it was possible to gain only a general knowledge of the history of the mining of a few of the numerous creeks, and of the mode of occurrence and origin of the pay gravels.

The writer is indebted to Mr. John Hopp for information regarding the results of Keystone drilling on Williams creek; and to Mr. J. G. McLaren for information regarding the results of drilling on Antler creek. Acknowledgments are due also to Mr. Lawrence Muller, manager of the Hopp mines, to Mr. C. W. Moore, manager of the New Waverly hydraulic mine, to Mr. L. A. Dodd, gold commissioner, to Mr. L. A. Bonner, and to many other mining men of the district.

GENERAL CHARACTER OF THE DISTRICT

ACCESSIBILITY

Barkerville area may be easily reached by the Pacific Great Eastern railway from Vancouver to Quesnel or by steamer from Prince George to Quesnel, and thence 60 miles by stage to Barkerville, or by automobile stage from Ashcroft to Barkerville. The Keithley district, 30 miles southeast of Barkerville, is reached by a road passable for automobiles from Williams lake to Quesnel Forks and thence 18 miles by a rough wagon road to Keithley. A pack trail connects Keithley and Barkerville, and wagon roads connect most of the important creeks in the Barkerville area.

[1] A paper on "Cariboo Placers and Lodes" by J. A. Macpherson also appeared in the Min. and Eng. Record, vol. XXIV, 1919.

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CLIMATE

Records of climatic observations at Barkerville are available from 1888 to 1921.

The mean annual temperature at Barkerville is 35·7 degrees, nearly the same as that of southern Manitoba. The temperature extremes throughout the year are, however, less than in southern Manitoba, the summers being cooler and the winters milder. The mean temperature for July, the warmest month, is 54 degrees, whereas at Winnipeg it is 66·2 degrees. The mean temperature for January, the coldest month, is 17 degrees, whereas at Winnipeg it is −4 degrees. The temperature rarely rises above 80 degrees in the warmest month or below −20 degrees in the coldest month and in some years these extremes are not reached.

The average annual precipitation (rainfall and melted snowfall) at Barkerville is 34·5 inches and is well distributed throughout the year. The monthly average for the summer months June, July, and August is 3·2 inches and is slightly greater than for the winter months. The average winter's snowfall is 185 inches. It varies greatly from year to year. In the winter of 1904-05 it was only 97 inches; in the winter of 1916-17 it was 258·3 inches.

It is probable, so far as climatic conditions are concerned, that dredging could be carried on in the area throughout nearly the whole year.

PHYSICAL FEATURES

Because of the considerable relief, Barkerville area is generally described as mountainous, but, as pointed out by G. M. Dawson[1], it is perhaps more correct to regard the region as a deeply dissected, high-level plateau, the plateau level being preserved only in the interstream areas. The Cariboo Mountain range, characterized by rugged peaks covered with perpetual snow, lies about 20 miles east of Barkerville and forms the eastern boundary of the plateau. In the vicinity of Barkerville, the plateau level is 6,000 to 6,200 feet above the sea. Most of the important gold-bearing streams (Figure 11), Antler, Grouse, Williams, Jack of Clubs, and Lightning, rise in the Bald Mountain plateau—so-called because it is largely above timber-line—above which rises mount Agnes, an isolated peak about 300 feet above the general plateau-level. Only the creeks flowing north, northeast, and northwest from Bald mountain are gold-bearing except some of the tributaries of Swift river. The creeks descend rapidly from the plateau-level, so that within a distance of 5 to 10 miles from their sources they flow in valleys, the bottoms of which are in places over 2,000 feet below the plateau-level. The valleys are narrow and steep-sided in the upper parts, but in places have the U-shaped cross-section characteristic of glacially eroded valleys. They broaden out in the lower parts, where they are deeply drift-filled and have alluvial flats with a general elevation of about 4,000 feet.

The remarkably flat-topped summits on the interstream areas, and the fact that the nearly level surface is formed by the truncated edges of a highly folded and steeply dipping series of sedimentary rocks—which were nearly horizontal when deposited—shows that the area was once mountainous and was worn down nearly to a plain. The deep valleys have been cut down below the plateau-level and are evidence of still further erosion of the bedrock, so that it is evident several thousand feet of rock have been eroded away in places. One of the conditions for the formation of rich placer deposits was, therefore, fulfilled, the others, also fulfilled, being that the rocks eroded were in part gold-bearing and the gold placers were preserved from erosion.

The area is well wooded except on the summits, and an abundance of timber, chiefly spruce, is available. The area in the immediate vicinity of Barkerville, as shown by old photographs, was almost entirely denuded of forest in the sixties, but has since become reforested (*See* Plates II A and B).

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[1] Geol. Surv., Can., Ann. Rept., vol. III, pt. II, 1887-88, p. 30 R.

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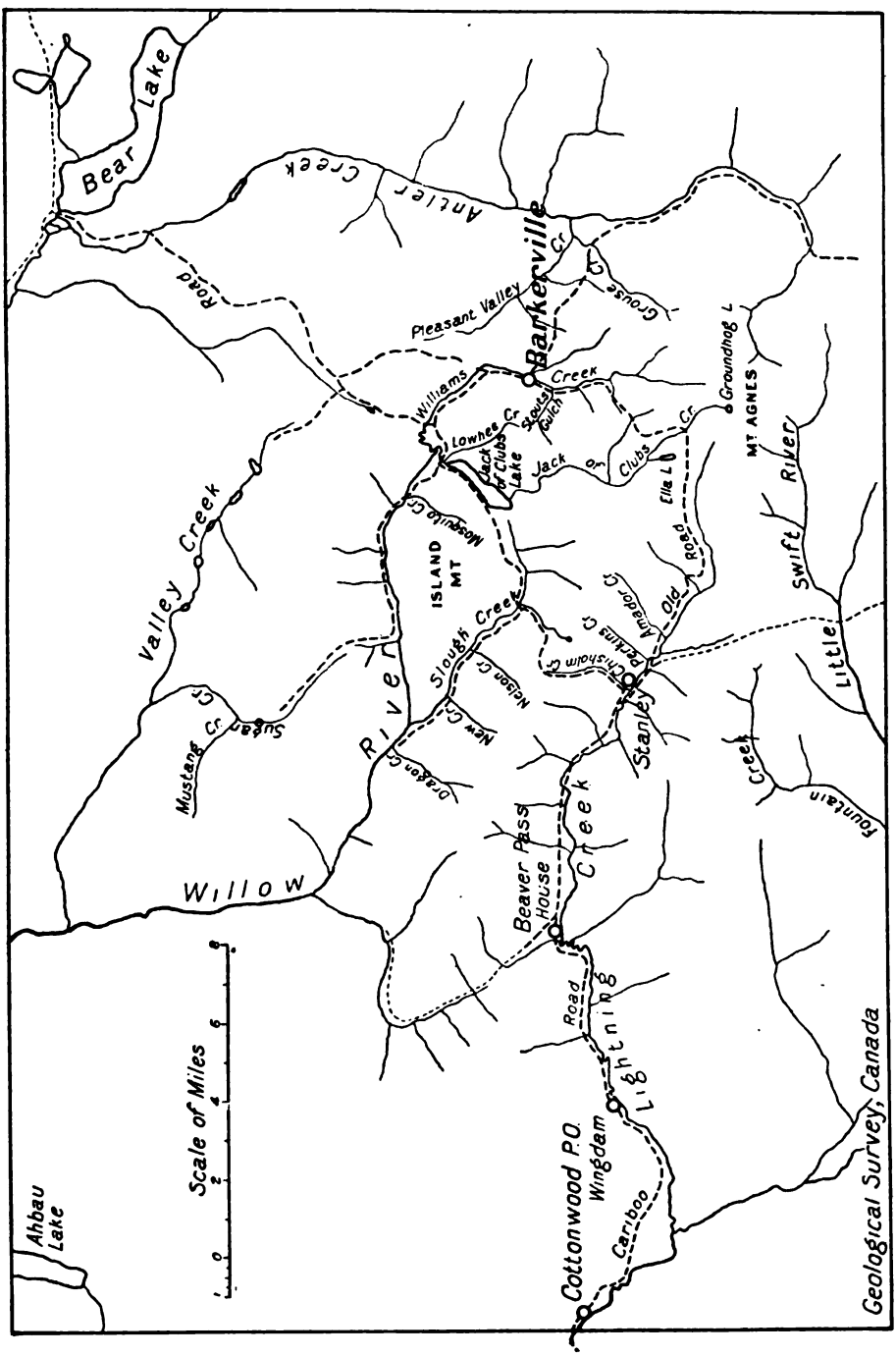

Figure 11. Barkerville district showing location of streams.

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GENERAL GEOLOGY

GLACIATION

A remarkable fact and one difficult of explanation is that, although the region was glaciated, the gold placers were not destroyed nor materially eroded. The gold-bearing gravels are in part post-glacial, but by far the most important deposits are preglacial or Tertiary. Their preglacial age is obvious from the fact that the placer deposits are largely buried beneath glacial drift, and because only by the erosion of considerable thicknesses of the bedrock, and concentration of the gold by stream action, could the gold placers have been formed.

Glacial drift is abundant in the area, and in places fills the valley bottoms to a depth of 100 to 250 feet. In many cases, it mantles the sides of the valleys up to over 1,000 feet above the valley floors and, in some places—as on Proserpine mountain—true boulder clay occurs at an altitude of 5,500 feet. At higher altitudes the drift is mostly very thin or is absent, but, as pointed out by MacKay,[1] erratics occur on some of the highest summits, at altitudes of nearly 6,500 feet. The glacial drift in the valleys is nearly all of local origin, but foreign boulders occur. For example, large boulders of conglomerate are fairly abundant in the upper part of Williams creek. Glacial striæ are well developed in places and are particularly distinct on both sides of Williams creek, a short distance above the canyon between Barkerville and the old town of Richfield. Here the striæ trend downstream and show that the ice eroded the bedrock of the valley sides, but did not affect the valley floor which retained very rich placer ground. A considerable area of bedrock, glacially striated and grooved, has been exposed by mining on Cunningham creek. It is stated that considerable quantities of gold were obtained from fissures and depressions in the bedrock at this locality, showing that erosion by the glacier had not been sufficient to remove entirely the preglacial deposits. Striæ also occur at other places in the area. In the valleys they nearly all trend downstream and were, therefore, probably formed by valley glaciers. Moraines formed by the valley glaciers occur in Lightning Creek valley near Stanley, and in Slough Creek and Grouse Creek valleys. These moraines were formed during the closing stage of glaciation, for they are well preserved and occur at the surface in the valley bottoms. There is, therefore, as was recognized by Tyrrell,[2] comparatively little evidence of the presence or effects of an extensive ice-sheet in this region during Pleistocene time. Nevertheless, the presence of erratics and boulder clay at high altitudes, and the foreign derivation of some of the drift in the several valleys, and the occurrence of boulder clay at altitudes too great to be referable to valley glaciers, all go to show that an ice-sheet of considerable thickness did exist.

The glacial drift consists in part of boulder clay and moraine material; in part of stratified sand and silt—the "slum" of the placer miner; and in part of stratified gravels and bouldery deposits. The boulder clay in most places consists of an upper yellowish unstratified clay containing few boulders, and a lower bouldery clay, occurring chiefly in the valley bottoms. The upper clay, probably, was formed from materials included in the ice and deposited after its melting; the lower clay was formed beneath the ice. The moraines are composed of materials deposited at the ends of the glaciers. In many places the stratified sands, silt, and gravel occur chiefly beneath the boulder clay and rest directly on the preglacial gravels and "slide-rock" of the valley floors. The stratified silt and sand above the general drainage level in some of the valleys and beneath the boulder clay, show that in the early stages of glaciation the northward drainage was blocked—probably by an advance of glaciers from Cariboo mountains—and formed glacial lakes. The sands and gravels protected both the preglacial gravels and the bedrock from erosion by the later glaciers.

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[1] Geol. Surv., Can., Sum. Rept., 1918, p. 42 B.

[2] "Was There a 'Cordilleran Glacier' in British Columbia?" Jour. of Geol., vol. 27, 1919, p. 57, J. B. Tyrrell.

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The main reasons, therefore, why the placers were not eroded by the glaciers are: (1) that they were partly protected by glacial outwash deposits; and (2) that the ice-sheet which covered the whole region was nearly stagnant. If valley glaciers alone had persisted throughout the Ice-age, the preglacial gravels would probably have been entirely removed, for valley glaciers as agents of erosion are much more effective than an ice-sheet—even of wide extent—that has a low surface gradient. Valley glaciers, however, did exist at the close of the Ice-age and they accomplished some erosion, especially in the upper parts of the creek valleys, which accounts for the absence in places of gold in the gravels.

The glaciation of the area is, in addition, mainly responsible for the exceptionally long life of this placer camp—long, that is to say, compared with that of many other alluvial fields. Although the early prospectors sometimes found the gold-bearing gravels only thinly covered by drift, they also found that in most places the gravels lay beneath a heavy burden of glacial deposits that obscured the ancient rock channels, and owing to their thickness and water-bearing character rendered difficult the recovery of the gold. A considerable part of the gold, therefore, was never touched. Had the area been unglaciated, almost all the gold would probably have been recovered within a few years after it was first attacked.

An interesting feature in connexion with this glaciation is that, so far as is known, only the one boulder clay or till sheet occurs and, as preglacial gravels are known to occur, it is probable the glacial period was—so far at least as the higher parts of the region are concerned—a unit.

ECONOMIC GEOLOGY

PLACER DEPOSITS

The placer deposits may be broadly divided into post-glacial and preglacial gravels, the preglacial being by far the more important. The post-glacial gravels form the surface gravels (except where buried by tailings) in the valley bottoms and in a few places on benches. Their gold content was derived partly by stream erosion of the glacial drift, which contains small amounts of gold included in it, and partly from erosion of the preglacial gravels and bedrock into which the present streams have cut in a few places. The area is largely drift-covered—especially the valley bottoms—and erosion, since the disappearance of the glaciers, has been limited. It is evident, therefore, that the post-glacial gravels cannot be of much importance, except locally.

The preglacial gravels consist of bench and creek gravels largely buried beneath the drift deposits, but some occur near the surface. Most of the Barkerville output was derived from them. The preglacial gravels cannot easily be distinguished from the glacial even where good sections are exposed down to bedrock, for both consist mainly of gravels derived locally and both may be well oxidized or may not. The preglacial gravels are mostly only a few feet in thickness, and are in places characterized by heavy iron minerals, and pebbles or boulders of galena and barytes, and occasionally scheelite. Many of the deposits too, are characterized by large angular slabs of rock known as "slide-rock," apparently an ancient talus. Blocks of this rock, and slightly waterworn gravel and boulders, are partly embedded in disintegrated bedrock or yellowish or bluish clay. The gravels are, in a few places, cemented by iron oxide. The gold in places extends downwards for several feet along the bedding planes and fissures in the bedrock. Residual gravels, that is gravels consisting principally of a resistant rock such as quartz, are present only in small quantities. The preglacial gravels are made up of schists, limestone, quartz, and igneous rocks, derived mainly from the Cariboo schist series named and described by Bowman.[1] The absence

[1] Geol. Surv., Can., Ann. Rept., pt. C, 1887.

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of residual gravels is probably due to the youthful character of the present valleys in which the streams have naturally a fairly high gradient and the present valleys coincide, approximately, with the ancient valleys. Residual gravels can be formed only in valleys having a very low surface gradient, for in valleys having a high gradient, fresh rock material is constantly being added to the gravels, which are eroded and carried away.

Bench deposits which occur on many of the creeks at various levels are nearly all confined to the present valleys and seldom cross the present drainage, for, as pointed out by Dawson[1], the courses of the ancient and present streams are very much the same. There are, however, many places where diversion—and even reversal—of stream drainage took place as the result of stream capture in preglacial time. In places, also, the irregular deposition of glacial drift has diverted the streams into new channels, a striking example of which is Black Jack canyon on Williams creek. A characteristic feature of several of the new channels—indicated by their narrow, steep-sided character—is that they rarely contain much gold. Some of these are mainly post-glacial in age, others are preglacial and are partly due to stream capture and possibly also to rejuvenation of the streams by uplift of the region. They contain little gold unless they have been cut down directly beneath the older higher channels, for any gold they happen to contain is the result of erosion of only a small thickness of rock, whereas the concentrations in the old channels are the result of the wearing down of great thicknesses of rock. The gold in the area is mostly coarse, so that little of it is now transported by the streams. Part of it has probably moved downwards, vertically, nearly as far as it has been transported horizontally. The current through the canyons being rapid, any gold fine enough to be transported by the stream would probably be carried through the canyon.

Very little flour gold or even fine scale gold is present; for apparently the streams in preglacial time had sufficient gradient to transport the fine gold out of the region to the lower Fraser, where it has gone to enrich the placers of that region. There is little difficulty, therefore, in saving the gold in the Barkerville district.

Boulder-like masses or pockets of the preglacial gold-bearing gravels are included in the boulder clay in places, especially in its lower, bouldery part. The upper, clayey part is almost free from gold as are also the stratified sands and silts and fine gravel known to the miners as "chicken feed"; but occasional nuggets are scattered through the glacial drift. There have been some notable instances in the district of the finding of masses of gold-bearing gravels included in the boulder clay, but because of their mode of occurrence, such masses are as a rule found only accidentally in hydraulic mining. Where the boulder clay is tight on the bedrock, and contains little gravel, there is little gold. This fact was well known by the early miners, and isolated masses of boulder clay in the upper part of Williams creek remain untouched to this day, although all the surrounding ground was worked. Many of the creeks contain, in their upper reaches, considerabe quantities of coarse bouldery deposits, in places rudely stratified. They are apparently glacial outwash deposits and are as a rule nearly barren of gold.

An instance of the sporadic occurrence of gold in this area was noted during the past summer. Two miners, George Moore and Joseph Spratt, working on the upper part of Walkers gulch, which empties into Williams creek at the old town of Richfield, recovered 7 ounces of gold in three days hydraulicking. The material washed was largely boulder clay, and averaged over $3 a cubic yard, the gold being derived apparently from gravels included in the boulder clay. There was very little gold on bedrock. It is probable that there are many such occurrences in the district.

Antler Creek

Antler creek, discovered in 1860, was the first creek of the Barkerville area found to be auriferous. The rich placers of the Barkerville area were not found by

[1] Geol. Surv., Can., Ann. Rept., vol. III, pt. II, p. 31 R.

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following the trail of fine gold up the Fraser and its tributaries, directly to this area. However, the theory of the miners that this fine gold had its source in a region where coarse gold would be found was undoubtedly the impelling force, as has been frequently pointed out, that led to the rapid discovery of the main placer fields. The theory was more or less sound in respect to Keithley, Harvey, and Cunningham creeks, southeast of the Barkerville area. In 1859, while placer mining was active along Quesnel river as far up as the Forks and Quesnel lake, a number of prospectors made their way up the north fork of the Quesnel, but lost the trail of fine gold at the falls, 5 miles below Cariboo lake; and it was not until the following year that Keithley creek, flowing southeast into Cariboo lake, was discovered. Late in the autumn of 1860 a party of prospectors, among whom were Rose, an American, and McDonald, a Canadian, crossed over the divide at the headwaters of Keithley creek and discovered gold on Antler creek. Little work was, apparently, done on the creek in 1860. The success of the miners becoming known at Keithley, a mid-winter rush ensued and when Gold Commissioner Nind arrived at Antler creek early in March, 1861, he found the snow 6 or 7 feet deep and the miners living in holes dug in the snow, and subsisting on the scanty supplies brought from Keithley.[1]

Antler creek rises in Bald Mountain plateau, flows southeast for several miles to Sawmill flat where it is joined by a tributary from the south, and then flows nearly north to form the headwaters of Bear river. Four miles north of Sawmill flat the creek turns to the west around a hill, to the right of which an old channel, partly drift-filled, extends to the headwaters of a branch of Cunningham creek in Cunningham pass (*See* Map 1941). This old channel is about 80 feet above the bedrock in the present stream channel of Antler and is a continuation of a bench that extends upstream along the left limit of Antler creek for about 3,500 feet and then crosses to the right bank. Above this point a small canyon extends for nearly a mile to the wide, shallow part, where most of the mining in 1861 was done. The remarkably rich and easily mined part of Antler creek was shallow ground extending for about 1½ miles along the stream above the canyon and below Sawmill flats. The daily output of the creek during the summer of 1861 is reported to have been over $10,000 and much of the ground is said to have yielded $1,000 to the square foot.[2]

The benches along the creek below the canyon and down as far as Cunningham pass have been mined, at intervals, partly by drifting and partly by hydraulicking. The early miners recognized that the present stream gravels would be enriched at those places where the present stream valley has been lowered by erosion and has cut across the more ancient stream valley, represented in part by the benches. One of these was at the mouth of the valley known as Whiskey flat where the Nason Company sank two shafts on the left bank of the stream and attempted to drift out into the channel. They are said to have spent, prior to 1875, $20,000 in unsuccessful efforts to test their ground. Work was resumed by a company of the same name in 1884 and was carried on nearly every summer until 1893, but with little success because of the porous, water-bearing character of the river gravels and the absence of any clay that would hold back the surface water. In 1888 the company succeeded in driving part way across the creek bottom, and obtained round, heavy gold at the rate of $1.50 to the bucket; but they were of the opinion that they had not struck the main lead.[3]

The old shaft of the Lothair Company, whose claim adjoins the Nason claim on the upstream side, was located, as shown on Bowman's map of Antler creek, nearly opposite the mouth of McBean creek. This company also appears to have been unable to mine the bedrock gravels in the present stream valley. The Bulger bench on the left limit of Antler a short distance below the mouth of McBean creek was mined in 1861. The Pittman and Porter bench claims on the right limit in the upper part of the Lothair were mined in 1861-62, but no information is available regarding their output. In Whiskey flat the best known claim was McBean bench. In

[1] Bancroft's Works, vol. XXXII, History of British Columbia, pp. 472-494.
[2] Ibid, p. 492.
[3] Ann. Repts., Minister of Mines, B.C., 1875-1893.

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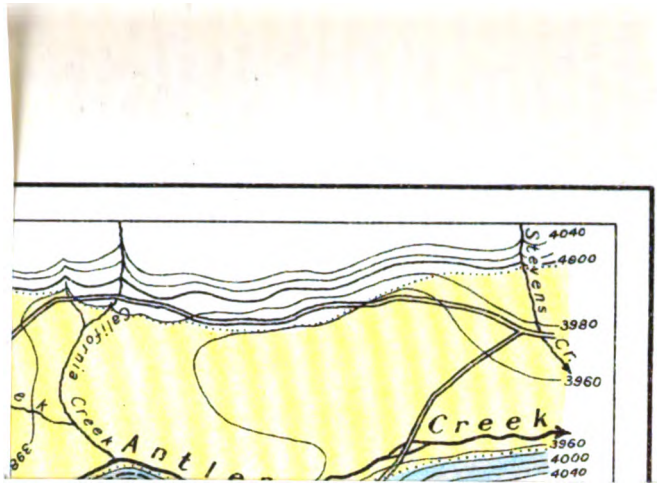

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Cunningham pass, at the lower end of Whiskey flat, the Yellow Lion Company found gold on bedrock in 1881. The claim is said to have paid well for several years.[1]

Wolf, California, and Stevens creeks which flow into Antler from the west, in the wide part below the Nason property, were all gold-bearing.[2] Tailings from hydraulicking in the tributary valleys form a part of the filling of the valley of Antler in this wide part.

The dredging ground of Antler creek consists of the Nason (real estate) claim, the Lothair (real estate) claim, and the Macdonald lease. It embraces the comparatively shallow part of the present stream bed, which begins to widen out in the lower part of the Nason claim. Keystone drilling, to determine the depths and gold values of the ground, was done by the Yukon Gold Company in 1915. A few borings were also made subsequently by the New Waverly Hydraulic Mining Company. The results of the drilling showed that the known dredging ground has a length of at least 4,000 feet; the pay gravels have an average width of 140 feet and an average depth of 48 feet, giving a total of 1,000,000 cubic yards. The ground is deepest in the Lothair claim where it has a maximum depth of 69 feet. The average value per cubic yard is 66·3 cents which is reduced to 45 cents to allow for gravels sliding into the pond and for other factors, the total recoverable gold content being estimated at $540,000. One bore-hole in the line near the Nason shaft showed a value of $6.74 per cubic yard. A check hole put down 2 feet away showed a value of $1.34½ per cubic yard and this figure was used as a basis in calculating the average value of the line of holes. The values show that this part of the stream channel is enriched by gold derived from the ancient channel as pointed out above. Twelve hundred and fifty feet of the upstream part of the property has not been drilled, but the values should approximate the general average and should bring the total recoverable gold up to $700,000. The gold is largely coarse and is mostly on or near the bedrock. The bedrock consists of steeply dipping schists which could be dredged without difficulty.

The creek has a grade of 1·4 per cent for 3,000 feet above the Nason shaft and 0·8 per cent from the Nason shaft down to the mouth of Stevens creek. The gravel is mostly fine, with few boulders over 6 inches in diameter and clay is absent. The absence of clay, in fact, has been the chief reason why it has not been found possible to mine the bedrock gravels by drifting. It is possible that a part of the nearly barren upper gravels might be removed by "booming." An excellent site for a dam is in the upper part of the Lothair claim, by means of which large volumes of water could be impounded and the water released automatically to flush out the upper gravels.

The fact that the present channel of Antler creek cuts across the ancient gold-bearing channel in the Nason, and upper part of the Lothair, claims suggests the inference that the ground will dredge up to the drillings. It is possible that the exceptionally rich ground, as shown by the borings on the lower part of the Nason, extends for some distance upstream.

Williams Creek

Williams creek, on which the town of Barkerville and the old town of Richfield (a mile upstream from Barkerville) are situated, heads in Bald mountain and flows north for 5 miles to "The Meadows" where it turns west and forms the headwaters of Willow river. The gold-bearing part of the creek, extending for 1¾ miles above Barkerville and 1 mile below, is naturally divided into two parts, of different characteristics, by the Black Jack canyon, about half-way between Barkerville and Richfield. The canyon is narrow and rock-walled, about 50 feet deep and 1,000 feet long. It forms a bend in the stream around a rock island, on the east side of which the preglacial stream flowed in a narrow valley. The filling of the old valley by glacial drift caused the present stream to be diverted into the new channel. This fact, too, was

1 Ann. Repts., Minister of Mines, 1881-84.
2 Dawson, G.M., Geol. Surv., Can., Ann. Rept., vol. III, pt. II, 1887-88, p. 123 R.

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known to the early miners and in 1862, one year after the discovery, the Black Jack tunnel was begun for the purpose of locating the old channel. In 1867 the property was worked as an hydraulic claim, the first in the area, and it was still being worked in 1890.[1] The drift deposits were eventually almost entirely washed out from the old channel and the stream now flows partly in one channel and partly in the other.

Discovery claim, at the lower end of the canyon, was located in 1861 by William Dietz after whom the creek was named. It proved to be one of the poorest claims on the creek.[2]

The part of Williams creek above the canyon is comparatively narrow and steep-sided. The first important discoveries of gold were made in this part of the creek between the canyon and Richfield. The post-glacial gravels were worked first, the underlying boulder clay being regarded as the bedrock; but the main "pay" was soon found on the Abbott claim by sinking through the boulder clay to the bedrock. It was probably the comparatively lean character of the upper gravels that led to the first naming of the creek as Humbug creek. The main "pay" on the Steele claim consisted of a blue clay layer 6 feet thick containing decomposed slate and gravel, the overburden being 8 to 18 feet thick.[3] This part of the creek was eventually worked by open-cuts from the surface to the bedrock. A poorly-defined bench 50 to 100 feet above the creek bottom occurs along the east side above the canyon and was also worked. The bench has a lesser gradient downstream than the present creek, and—a short distance above Richfield—is nearly at the level of the present creek. The upper part of the creek was found to be barren; the pay stopped abruptly about three-quarters of a mile above Richfield, but was again met with considerably higher up in the tributary valley, McCallum gulch.[4]

The lower part of the creek, below the canyon, is comparatively wide and flat-bottomed, the valley flat averaging about 400 feet in width (*See* Map 1942). Here, the ground is deep, and was mined by shafts, 40 to 80 feet deep, and by drifts. One of the first shafts in this part of the creek is still to be seen in Barkerville. It was put down early in 1862 by Billie Barker, after whom the town was named, and was 52 feet deep.[5] As in the upper part of the creek, here also there were two pay-streaks, one in the post-glacial gravels and the other in preglacial gravels on bedrock. The latter gravels are separated from the upper by glacial deposits consisting in part of boulder clay and in part of stratified silt and gravel. The post-glacial gravels are concealed by tailings that average possibly 20 feet in thickness, and were chiefly derived by hydraulicking in Stouts gulch which enters Williams creek from the west at the lower end of the canyon. The preglacial gravels were mined chiefly in the sixties and were largely worked out from the canyon down nearly to the meadows, where the excessive pressure of groundwater prevented mining. These gravels were remarkably rich. According to the estimate given in the Report of the Minister of Mines, British Columbia, for 1896, this part of the creek produced between $8,000,000 and $9,000,000. The post-glacial gravels also were found in places to be rich. At the famous Cameron claim, about one-half mile below Barkerville, the ground was sufficiently rich to be worked in a series of levels from the surface to bedrock.[6] The claim was located on the east side of the valley flat, the depth to bedrock being 40 feet.[7] There were a few rich claims below the Cameron claim, but farther downstream near the meadows, where the ground was about 80 feet deep, the gold was light and scaly.[8] The richest part, as noted on Bowman's map of Williams creek, was opposite the mouth of Conklin gulch and for about 1,500 feet downstream.

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[1] Ann. Rept., Minister of Mines, B.C., 1890, p. 360.
[2] Bancroft's History of British Columbia, p. 497.
[3] Ibid, p. 496.
[4] Bowman's map of Williams creek, Geol. Surv., Can., Ann. Rept., 1895.
[5] Howay and Scholefield, "British Columbia from the Earliest Times to the Present," vol. II, p. 83, 1914.
[6] Milton and Cheadle, "The Northwest Passage by Land," p. 362.
[7] Bowman's map of Williams creek.
[8] Dawson, G. M., Geol. Surv., Can., Rept. of Prog., 1876-77, p. 112.

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There were also several rich claims above Barkerville, where the ground was originally 60 feet deep and in 1885—because of the accumulation of tailings—was 80 feet deep.[1]

The most important tributary of Williams creek below the canyon is Conklin gulch, which enters from the east opposite Barkerville. It was mined by drifting throughout a distance of nearly 2 miles, the ground varying in depth from 20 feet, in the upper part, to 90 in the lower.[2] The famous Ericsson and Sawmill claims were located in the lower part, near Williams creek, and the equally famous Aurora was on a bench on the right side, near the mouth. On the right limit of the gulch, near its mouth, are two benches, above the level of Williams Creek flat, and the present stream flows between rock rims nearly at the level of the flat. The deep channel, graded to the bottom of Williams Creek valley, is buried beneath drift. The three claims mentioned above are credited with having produced $1,500,000 in gold.[3]

The Forest Rose property, which was originally mined by a deep shaft and by drifting, and was later worked as an hydraulic mine for over thirty years, is a buried channel running nearly parallel to Williams creek in its lower part, and lies a short distance to the east of this stream (*See* Map 1942). The first hydraulic work on the property began at the St. George cut at the meadows. The St. George property was originally the Prairie Flower, as shown by records in the office of the gold commissioner at Barkerville. The bedrock in the cut was not reached until after several years' work and not until the cut had been carried for some distance up the old channel.[4] The old rock channel is wide, has a low gradient, and is about 50 feet above the bedrock in the adjacent part of Williams creek. It is evidently an old channel of the latter, as is generally recognized by the miners, and not, as was formerly held, a high-level channel extending along the east side of Williams creek from Conklin gulch.[5]. The channel apparently leaves Williams creek at about the location of the old Cameron claim. The part between the head of the Forest Rose pit and Williams was probably mined by drifting in the early days. The small hydraulic pit extending from near the Forest Rose shaft to Williams creek was made in recent years in an attempt to remove the overburden from part of the old channel by washing it directly into Williams creek, for it was found that the grade of the bedrock in the Forest Rose pit was too small to permit of a working gradient for the sluice boxes. Hydraulicking was abandoned in 1912. Although there is little evidence of a high channel occurring between the Forest Rose and Conklin gulch, it is stated by William Brown, of Jack-of-Clubs creek, that the California tunnel shaft 600 feet south of the Forest Rose shaft (shown on Map 1942) was 40 feet deep and that 40 ounces of gold were recovered by drifting from the bottom of the shaft. As the bottom of this shaft is nearly 100 feet above the bedrock in the Forest Rose channel it is evidently in a different channel. However, little gold appears to have been found in other workings along the supposed high level, buried channel between the Forest Rose and Conklin gulch, and it is possible the gold in the California tunnel workings was in a small creek channel tributary to Williams creek.

The Prairie Flower is stated to have had an output of $100,000 and the Forest Rose $480,000, prior to 1896.[6] The latter has produced considerable amounts of gold since 1896. William Brown states that attempts were made in the early days to mine the bedrock gravels in the Forest Rose channel at the meadows, but unsuccessfully, owing to the pressure of underground water. The facts that this channel is about 50 feet above the channel of Williams creek and that it was apparently richer in its lower part than the channel of Williams creek near the meadows, indicate that dredging ground may be found at the lower end of the Forest Rose. This ground has not been tested by borings.

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[1] Bowman's map of Williams creek.
[2] Dawson, G. M., Geol. Surv., Can., Rept. of Prog., 1876-77, p. 135.
[3] Ann. Rept., Minister of Mines, B.C., 1896, map of Williams creek.
[4] Ann. Rept., Minister of Mines, B.C., 1886, p. 196.
[5] Geol. Surv., Can., 1895, Bowman's map of Williams creek.
[6] Ann. Rept., Minister of Mines, B.C., 1896, map of Williams creek.

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The reasons why Williams creek was the richest creek in the region and why certain parts of it were richer than other parts are fairly obvious when the history of mining on the creek and the physical characteristics of the creek are considered. The creek valley trends at an angle of about 45 degrees across the strike of the schists and through a belt in which occur numerous quartz veins, from which the gold was probably derived. The veins are mostly nearly parallel to the strike of the rock, and are apparently most numerous in the zone along the part of the creek where the placers were richest. The barren upper part of the creek was due, probably, in part to glaciation. In the rich part of the creek above the canyon a bench occurs, but it was partly cut away by the present stream. The present stream channel was enriched by gold from the bench and coincides very closely with the ancient channel. At the canyon the old channel was rich and the new channel for reasons already pointed out was of little value. Below the canyon there are no important ancient channels occurring as benches of the creek except the Forest Rose channel. There are, however, several gold-bearing channels tributary to the creek. The present channel, as far down as the old Cameron claim, coincided with the ancient channel, so that large quantities of gold derived from the wearing away of a great thickness of rock were concentrated in it; and the structure and character of the bedrock throughout the creek bottom were ideal for retaining gold. The remarkably rich character of the post-glacial gravels at the Cameron claim was due probably to the present stream cutting into the bench of the Forest Rose channel.

Attempts have been made, notably by the Cariboo Gold Fields Company (using at first an hydraulic lift and later a bucket elevator) to mine the whole of the gravels of the part of Williams creek below the canyon, for it was generally held that because of the crude methods of mining and of saving the gold at the time when nearly all the mining was done on this part of the creek, and because of the large amounts of gold recovered, there must be a considerable amount remaining. In this connexion, the following observation of G. M. Dawson[1] is of interest. "I do not think it would be an extravagant statement to say that the quantity of gold remaining in the part of Williams creek which has been worked over, is about as great as that which has been already obtained." It was also known that there were in places upper pay-streaks which were not mined in the early days because the bedrock gravels were much richer and because of the high cost of mining. The attempts by the Cariboo Gold Fields Company to mine the gravels failed because of mechanical difficulties in the operation of the lift and elevator.[2] The location of the elevator is shown on Map 1942.

The dredging ground on Williams creek extends from the lower end of the canyon or mouth of Stouts gulch to the meadows, a distance of 8,000 feet. The ground was tested by Keystone drilling in 1914 and 1915, eight lines of bore-holes being put down at fairly regular intervals across the valley.

The results of the borings showed that the pay gravels average nearly 240 feet in width and have a maximum depth of 76 feet, with an average of 59 feet. The average value is 31 cents per cubic yard, which would probably have to be cut down 2 or 3 cents to allow for gravels sliding into the pond and for other factors. The total amount of pay gravels is approximately 4,000,000 cubic yards. Owing to lack of borings there is some doubt as to the yardage and values in the part above Barkerville.

For the reasons stated above it is surprising that the results of the drilling did not show higher values, and it seems possible, when the ground is actually dredged, that in places it will produce higher values. It is possible, also, for the reasons stated above, that dredging ground may be found at the lower end of the Forest Rose, and in places in the Williams Creek and Willow River flats. It is known that the ground in the flats or meadows is for the most part too deep for dredging. There are, however, favourable localities such as the flat or the mouth of Mosquito creek, and at

[1] Geol. Surv., Can., Rept. of Prog., 1876-77, p. 114.
[2] Ann. Repts., Minister of Mines, B.C., 1889, p. 621, and 1903, p. 60.

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the mouths of Eureka and McArthur creeks which empty into Williams creek at the meadows. At these places the post-glacial gravels were, probably, enriched by gold from the tributary creeks.

The bedrock of Williams creek consists of schist and limestone beds dipping steeply towards the northeast. The rock is mostly soft and could be easily excavated in dredging.

Possible objectional features of the Williams Creek dredging ground are the depth of the deposits, the timbers in the old underground workings and in the bedrock drain which was built in 1865-66 and extends throughout the area, and the presence in places of boulder clay. It is possible that much of the underground workings has caved. The gravel deposits contain few large boulders and the boulder clay occurs only in places. It is possible, too, that a considerable part of the tailings which form a nearly barren overburden might be removed by "booming." An excellent site for a dam is at the lower end of Black Jack canyon, in which large volumes of water could be impounded to flush out the tailings. The creek, from the lower end of the canyon to the meadows, has a surface gradient of 2·6 per cent. During the past few years the creek itself has cut down the tailings in places as much as 4 feet. The lowering of the creek bed at Barkerville, which is protected from creek floods by a bulkhead, would also make it possible to work Conklin gulch to the best advantage, either by hydraulicking or by dredging, for, as already pointed out, the ground is deep in the lower part near Williams creek and this was the richest part of the gulch.

There is, possibly, dredging ground on Lightning creek and at other places in the district also. The writer's investigations, however, were confined chiefly to the areas described above.

SUMMARY

Gold dredging has not as yet been attempted in Barkerville area, although it has been known for many years as a suitable dredging proposition. But the high cost of machinery, of supplies in general, and of transportation, has so far been a deterrent to speculation. There is, however, a probability of dredging being started soon on Antler creek, and possibly, at other places in the region. The results of Keystone drilling on Antler and Williams creeks have shown that, in parts of the creeks, gold to the amount of at least $1,800,000 exists, of which the greater part is recoverable. In this paper an attempt has been made—by reciting the history of mining on the creeks and describing their physical characteristics—to show that the estimates of gold values, as evidenced by the borings, are moderate and that the known dredging ground may possibly be extended.

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GEOLOGY OF THE NORTH THOMPSON VALLEY MAP-AREA, B. C.

By W. L. Uglow

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INTRODUCTION

The North Thompson Valley area extends from Fishtrap rapids, 27 miles north of Kamloops, to the vicinity of Boulder (Figure 19). The east and west boundaries of the area are from 3 to 10 miles on each side of the river, sufficiently far apart in most cases to include the slopes of the Thompson trench and a part of the adjoining plateau. The Canadian National railway fringes the east bank of the North Thompson throughout the length of the sheet.

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Plate I.

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The geology was plotted on an excellent topographical base map made by D. A. Nichols, Geological Survey, during the seasons of 1918 and 1919. The rugged character of most of this country, and the thick timber, made mapping difficult, and it is a pleasure to acknowledge the extent to which the base map facilitated the work of the geologist.

The geological mapping was done on a scale of 4,000 feet to 1 inch. Traverses were run by the Brunton compass and aneroid method. Three and one-half months during the summer of 1921 were occupied by this work. Special attention was paid to the coal and mineral deposits. Short trips were taken outside the boundaries of the sheet, particularly to correlate the geology of the Adams and Barrière Lakes districts, as described by Dawson and Daly, with that of the North Thompson valley to the west.

The progress of the work was greatly facilitated by the courtesy and assistance of the settlers of the district. Special acknowledgments are due to the officers of the staff of the Chu Chua Coal Company; to W. J. Smith of Louis Creek; to J. J. Smith of Chinook Cove; and to George Fennell of Chu Chua. Very valuable assistance was given at times by D. A. Nichols, whose suggestions were the means of saving considerable time in geological mapping.

C. O. Swanson rendered efficient assistance in every branch of the work; and on occasions he was allotted semi-independent investigations. C. J. Cock also acted as field assistant.

PREVIOUS WORK

Previous geological investigations of this and adjacent areas had been made by the following members of the Geological Survey:

A. R. C. Selwyn[1] in 1871 made a traverse up North Thompson River valley from Kamloops and continued his reconnaissance beyond Tête Jaune to the Rocky mountains. He gives some preliminary notes on the occurrence of the Lower Cache Creek series, and the Tertiary lavas of the North Thompson; and on the granite gneiss and mica schist series near Raft river.

G. M. Dawson[2] in 1877 made a reconnaissance geological map covering 250,000 square miles of southern British Columbia. He reported briefly on the geology of North Thompson River valley, as far north as the Indian reservation near Chu Chua. He describes the first detailed section of the Tertiary coal measures, which are exposed in the valley of Newhykulston creek. His map, on a scale of 8 miles to 1 inch, is exceedingly general, and its northern boundary passes just south of the present village of Chu Chua.

G. M. Dawson[3], during the seasons of 1888, 1889, and 1890, geologically mapped the area of the Kamloops sheet (Figure 19). This work was done on a scale of 4 miles to 1 inch and embraced an area of 6,400 square miles. The areal and structural geology was, of necessity, done in a broad and general fashion, but with certain detailed examinations and sections in some of the crucial areas. His correlation of geological series was carried out in a tentative manner from the eastern slopes of the Coast range across the Interior plateau to the Selkirk and Rocky mountains. In many respects, it was based on the occurrence in widely separated districts of similar lithological successions of formations. Dawson describes the geology of the North Thompson valley from Kamloops to Chu Chua, and the distribution of the formations is shown in the extreme northeastern corner of his map. The structure, petrography, and economic geology of this part of the valley are dealt with in some detail. No new information is presented with regard to the Tertiary coal measures on Newhykulston creek.

G. M. Dawson, in the years following the completion of his Kamloops report, geologically mapped the area of the Shuswap sheet, which immediately adjoins on

[1] Geol. Surv., Can., Rept. of Prog., 1871-72.
[2] Geol. Surv., Can., Rept. of Prog., 1877-78.
[3] Geol. Surv., Can., Ann. Rept., vol. VII, N.S., 1894.

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the east (Figure 19) and slightly overlaps the Kamloops sheet. The Shuswap map includes an area of 6,400 square miles on a scale of 4 miles to 1 inch. Unfortunately Dawson was unable to complete his Shuswap report, so that the only published record of his results is embodied in his Shuswap geological map[1] and its marginal notes.

R. A. Daly,[2] in 1911 and 1912, carried on a geological survey of a belt of country paralleling the Canadian Pacific railway from Clan William on the east to a point 11 miles east of Kamloops. He extended his mapping to include the shores of Adams and Shuswap lakes, and outlined a general revision of Dawson's correlation. The work of the present writer in 1921 was extended easterly to the shores of Adams lake, and an areal connexion was thus established with the work of Daly.

TOPOGRAPHY AND CLIMATE

The North Thompson valley lies near the eastern margin of the Interior plateau. The strip of country included in the North Thompson Valley map-area is chiefly confined to the flat valley bottom and the rather steep valley slopes. In places, the map extends easterly from the lip of the valley to take in parts of the relatively flat uplands.

North Thompson river has entrenched itself from 2,500 to 3,000 feet below the level of the plateau. The gently undulating plateau country above altitudes of 3,500 to 4,000 feet is in very marked topographical contrast with the steep and in some places, rugged and rocky sides of the valley (Plate III A). The lower slopes are finely terraced, whereas the valley bottom is unusually flat and has an average width of one mile. Here and there isolated knolls and ridges stand in the middle of the valley, erosion remnants whose tops still rise very nearly to the general level of the plateau (Plate III B).

A large part of the district is drift-covered and well timbered. The chief areas of exposed rock are confined to the more rugged portions of the sides of the valley, the stream and river canyons, and the few monadnocks which rise above the plateau.

The area of the sheet lies just beyond the northeastern margin of the "Dry belt". The sage-brush country, so characteristic of Kamloops and the valley of Thompson river, does not extend northerly as far as Fishtrap rapids, a few miles south of which is a rather abrupt transition from treeless to timbered country.

The climate is warm and comparatively dry in summer with occasional rains. The precipitation is not sufficient, however, to render the flat terrace-lands arable, without irrigation; but barren-looking valley flats may be converted by irrigation into rich fruit-growing ground.

GENERAL GEOLOGY

GENERAL STATEMENT

The lower formations of the district, namely the Badger Creek, Fennell, and Barrière, consist of a series of quartzite, quartz slate, micaceous quartzite, sericite schist, chlorite schist, limestone, dolomite, argillite, argillaceous schist, greenstone pillow lava, with intrusive gabbro and diorite masses. They were included in the Cambrian system by G. M. Dawson, but later work shows this correlation to be doubtful. They are here classified as Precambrian or late Palæozoic.

These rocks are intruded by dykes, sills, stocks, and a batholith, consisting of granodiorite, granite, quartz diorite, micropegmatite-pyroxenite, alkaline syenite, aplite, and pegmatite. The age of these intrusives is not definitely known, but they belong, probably, to the period of Coast Range intrusion.

The above-mentioned formations are overlain unconformably by a series of late Eocene sediments consisting of basal conglomerate, arkose, arenaceous shale, and coal,

[1] Geol. Surv., Can., Map 604, 1898.
[2] Geol. Surv., Can., Mem. 68, 1915.

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which are confined to certain protected re-entrant positions near the bottom of the North Thompson trench. They are erosion remnants of a much more widespread series of mechanical and organic sediments. These sediments are unconformably overlain by a thick cover of Miocene augite-hornblende andesite flows, which have baked and somewhat metamorphosed the Eocene sediments. These two Tertiary formations have been considerably faulted and eroded, and, later, covered by glacial drift. Post-Pleistocene lava was found in Mann creek, overlying Recent stream gravels.

The North Thompson river occupies an antecedent course inherited from Cretaceous times. Its Cretaceous valley is still preserved as a slight depression in the uplifted Cretaceous peneplain.

The North Thompson valley was developed at least to its present depth in Middle Eocene time, for the Chu Chua (Eocene) sediments are now found along its lowest slopes. The valley was later flooded by Miocene lavas, and was re-excavated during the late Tertiary. Evidences of extensive glaciation are found in the valley, and on the highest peaks up to an altitude of 7,500 feet.

Several prospects are located in or near the map-area. The most important metalliferous deposits known are the Gold Hill, carrying free gold with galena; the Wind Pass and the Sweet Home, carrying free gold, magnetite, and native bismuth; the Queen Bess, a silver-zinc-lead deposit; and the Homestake, a silver-lead-barite deposit near Adams lake. The chief economic interest of the area, from a mining standpoint, is the occurrence of coal in the Eocene measures at Chu Chua. During the summer and autumn of 1921 active development and mining was being carried on by the Chu Chua Coal Company.

Table of Formations

Formations			Rock types
Quaternary	Recent		Lava River gravels, sands, silts, "White Silts" of Dawson
	Pleistocene		Glacial drift
	Unconformity		
Tertiary	Miocene	Skull Hill	Hornblende andesite Augite andesite Andesitic breccias Amygdaloidal andesite and basalt
	Unconformity		
	Eocene (Middle or Upper)	Chu Chua	Sandy shale Coal seams Arkosic sandstone Intraformational conglomerate Basal conglomerate
	Unconformity		
Mesozoic (?)	Jurassic (?)	Peterson Creek stock Baldie batholith Sills Sills Darlington stocks	Porphyritic alkali syenite Granite, porphyritic granodiorite Biotite granodiorite, quartz diorite Micropegmatite-pyroxenite Hornblende granodiorite, hornblende granite, orthogneiss

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Table of Formations—Continued

Intrusive Contact

Palæozoic or Precambrian		Barrière	Quartzite, sericitic quartzite, sericite schist, quartz pebble conglomerate, argillite, crystalline limestone, chlorite schist, schistose amygdaloidal lava.
		Fennell	Ellipsoidal (pillow) greenstone, gabbro and diorite sills, chert, volcanic breccia.
		Badger Creek	Slaty quartzite, quartz slate, biotite schist, dolomite, hornblende schist.

DETAILED DESCRIPTIONS OF FORMATIONS

Badger Creek Formation

The Badger Creek formation consists of a series of metamorphosed sedimentary and volcanic rocks, now largely schistose. They are predominantly grey, green, and greyish-black. The rocks are of the following types beginning with the highest members:

Schistose andesitic tuff, a transitional type between this and the Fennell formation.
Biotite schist.
Micaceous, thin-bedded, flaggy quartzite.
Dolomitic quartzite.
Quartz slate.
Silicified argillite.
Thin, fine-grained, dolomite and limestone beds.
Hornblende schist.

The series is intruded by small sills of granite and dykes of pegmatite which have limited outcrops, but which are believed to be connected with the Darlington granodiorite.

The Badger Creek formation is the lowest stratigraphic unit in the map-area. It is exposed (1) in the vicinity of Badger creek, where the formation crosses North Thompson river in a northwesterly direction; (2) north of Peterson creek on the west side of North Thompson river; and (3) in elongated strips in the neighbourhood of Thuya and Montigny creeks, and to the west of the crest of Baldie. These areas are unconnected and their rocks are referred to the Badger Creek formation chiefly on the basis of their lithology.

The dips vary from 0 degrees to 90 degrees, and in general the beds are steeply inclined.

In the belt which crosses North Thompson river at Badger creek,[1] the most complete section of the formation is exposed. The structure at this place is a gentle anticline, as shown in the structure section on line A_1-A_2-B (*See* Map 1945). The crest of the anticline is well exposed along the road 1½ miles northeast of the mouth of Badger creek. A section of the northeasterly limb of the anticline shows a thickness of about 3,500 feet.

In the area north of Peterson creek the rock relations are considerably obscured by a heavy mantle of timber and glacial drift, and the formation is broken up and metamorphosed by intrusions of Darlington granodiorite. This section is, therefore, only tentatively correlated with the Badger Creek formation.

In the Thuya and Montigny Creeks, and Mount Baldie areas, only narrow strips, consisting chiefly of quartz slate, thinly-bedded micaceous quartzite, and minor amounts of limestone and chlorite schist, are exposed, so that the assignment of these

[1] Geol. Surv., Can., Ann. Rept., vol. VII, N.S., 1894. Plate of sections.

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rocks to the Badger Creek formation is also tentative. Just west of the crest of mount Baldie, the westerly-plunging contact of the Baldie granodiorite truncates the quartzite and quartz slate beds of this formation.

Age and Correlation. No data were obtained within the map-area which would definitely aid in establishing the age of this formation. It is equivalent to the Niskonlith series (Lower Cambrian) of Dawson.[1] It has a distinct Cordilleran trend, and Dawson shows it to extend southeastwards with one gap, to the vicinity of Niskonlith lake.

Fennell Formation

This formation consists chiefly of a complex of altered basic rocks of intrusive, extrusive, and fragmental characters. It covers a larger area than any other formation within the boundaries of the sheet, and extends from its southern to its northern edges. It is classified by Dawson[2] as a lower part of his Adams Lake series.

South of Barrière river, the Fennell formation is made up of chlorite schist, slightly schistose fine-grained greenstone, with beds of schistose tuffs. These rocks conformably overlie the upper part of the Badger Creek formation and have a gradational contact with the latter. They are intruded by dykes and sills of diorite and gabbro of medium to coarse grain, in which the ferromagnesian minerals are sufficiently chloritized to give the rocks dull green colours.

North of Barrière river, the east side of North Thompson valley is bordered by abrupt, smoothly glaciated bluffs of brownish-weathering medium- to fine-grained greenstone (probably metabasalt). These bluffs constitute the Chinook mountains and Genier hill. In the vicinity of Chu Chua this formation spreads and occurs in somewhat isolated ridges in the middle of the main river valley. Examples of these ridges are Fennell mountains, mount Olie (Plate III B), and Queen Bess ridge. These ridges present the most striking topographic features of the sheet. The rocks composing them are mostly ellipsoidally weathered greenstone, associated here and there with sill-like and dyke-like masses of altered hornblende gabbro. Their most characteristic trait is their pillow structure (Plate IV A). This is exceedingly well shown on the cliff sides near Genier lake and along the Canadian National railway between Chu Chua and Mount Olie. They are interpreted as lava flows, probably of submarine origin.

Lenticular masses of thinly-bedded grey to white chert occur in association with the pillow lavas. This chert is formed, probably, by the interaction of the lava with sea water and its association recalls that of submarine lavas and chert beds of the Lake Superior iron district,[3] of county Tyrone, Ireland,[4] of the Isle of Man,[5] of Hawaii,[6] of Newfoundland,[7] and other districts.

A close examination of the "pillows" brings out the structure illustrated in Plate IV B. The outer parts of the "pillows" are dark bluish green, dense, and minutely fractured. The spaces between the broken parts of the peripheries and between adjacent "pillows" are filled with chert or chalcedonic quartz, probably of similar origin to the chert beds mentioned above. The cores of the "pillows" are slightly less dense than the outsides, and show concentric rings of much altered greenish amygdules. Coarse-grained calcite is associated here and there with the chert of the inter-pillow spaces.

In places long narrow lenses and beds of fine-grained white limestone or dolomite occur within the greenstone. These also seem to be the result of some process of interaction of the basic lavas with seawater and hence are of inorganic origin and non-fossiliferous.

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[1] Bull. Geol. Soc. Am., vol. II, pp. 165-176.
Geol. Surv., Can., Ann. Rept., vol. VII, N.S., 1894, p. 31 B.
[2] Geol. Surv., Can., Ann. Rept., vol. VII, N. S., 1894, pp. 102-108 B.
[3] U.S. Geol. Surv., Mon. 52, pp. 506-512.
U.S. Geol. Surv., Mon. 36, pp. 112-124.
[4] Geikie, "Ancient Volcanoes of Great Britain," vol. I, pp. 240-241.
[5] Idem, vol. II, p. 24.
[6] Dutton, "Hawaiian Volcanoes," U.S. Geol. Surv., 4th Ann. Rept., 1884, pp. 95-96.
[7] Daly, "Variolitic Pillow Lava from Newfoundland," Am. Geol., vol. 32, 1903, p. 77.

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Within this formation, at several places north of Chu Chua, long, narrow, dyke-like masses of buff-coloured siliceous ferrodolomite occur. These masses show gradational contacts with the greenstone, and are evidently the results of the carbonatization of belts of the greenstone along zones of shearing. They are important as the country rock of some of the mineral deposits, notably the Gold Hill and the Queen Bess. They are locally called dykes. Most of the greenstone has sufficient secondary calcite and dolomite scattered through its mass to produce a ready effervescence with hydrochloric acid. The liberation of calcium and magnesium carbonates during the process of the uralitization and chloritization of the ferromagnesian minerals accounts, probably, for the occurrence of at least some of the material of the ferrodolomite zones.

Structure. The exposures of the Fennell formation lying to the north of Barrière river and to the southwest of Louis creek were not found in areal connexion. The Fennell rocks which immediately overlie the Badger Creek formation southwest of Louis creek, are chlorite schists which grade upward into massive fine to medium-grained greenstones (meta-andesite and meta-basalts) in the vicinity of Blucher Hall. The lithological similarity of the greenstones immediately south of Blucher Hall, and for several miles thence in a southern direction up the valley of Louis creek, to those north of Barrière river is the reason for their correlation.

The areal geology indicates quite positively the position of a fault zone striking in a northeast direction up the valley of Barrière river (Figure 19). The block of country north of Barrière river appears as if it had been offset in an easterly direction with relation to the country south of the fault. The actual direction of the fault movement cannot be determined. With this interpretation, the belt of Fennell rocks north of Barrière river would correspond with that part lying on the western flank of the Badger Creek anticline near Skull hill (Structure section A_1-A_2-B).

As shown in the structure sections on lines C-D and E-F (*See* Map 1945) the northern part of this formation is believed to be in synclinal attitude, with the upturned edges of the underlying Badger Creek quartzites and quartz slates showing along its east and west margins.

Age and Correlation. No information tending to determine the age of this formation was obtained as a result of the season's work. The series corresponds to, and is in areal connexion with, the lower part of Dawson's Adams Lake series of Cambrian age occurring along the upper reaches of Louis creek.[1] It lies immediately below Daly's Bastion schists of Skaam bay, Adams lake, and is probably identical with his greenstones ("probably in part intrusive") of pre-Beltian age, as shown on his map of Shuswap lake.[2] It does not correspond with Daly's Adams Lake greenstones (pre-Beltian) which represent only the upper part of Dawson's Adams Lake series.

Barrière Formation

This formation consists of metamorphosed sediments, with minor amounts of volcanic flow and fragmental rocks. It is exposed chiefly in the country between Barrière river and Louis creek, and extends continuously eastward to Adams lake. A small section of these rocks occurs in the immediate southwest corner of the map, between Poison and Whitewood creeks.

The prominent petrographic types are grey and black-banded argillite, with cleavage crossing the bedding planes; brownish-weathering, fine-grained sericitic quartzite, which is characterized by the thinness (½-inch to 1-inch) and persistence of its individual beds; brownish to buff-coloured sericite schist; fine-grained, white to grey, massive limestone; dolomitic quartzite; schistose quartz pebble conglomerate; silicified argillite; talc schist; white, glistening, fissile, sericite schist; greyish green tuff; and schistose amygdaloidal metabasalt.

[1] Geol. Surv., Can., Ann. Rept., vol. VII, N.S., 1894, p. 108 B.
[2] Geol. Surv., Can., Mem. 68, 1915.

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Structure. The rocks of this formation on the western and southern slopes of Barrière and Dixon mountains and mount Fraser, form a very marked topographic unit. They have a fairly uniform strike varying between due east and south 60 degrees east, and they dip 35 degrees to 50 degrees to the northeast. In mount Armour, which is separated from Barrière mountains by a broad alluvial flat, the strike and dip vary as shown by the pattern on the geological map until they coincide with those of the Fennell schists at the junction of the two formations.

A vertical north and south section from Blucher Hall to Barrière river shows a thickness of over 32,000 feet of beds. The series, however, has been strike-faulted in several places in such a manner as to cause repeated duplications. Three of these faults are located on the map. Their courses could not be closely ascertained on account of the covering of timber and drift, but zones of very marked brecciation combined with topographic breaks indicate approximately the positions and trends of the fault zones. No estimate could be formed of the actual formational thickness exposed, but it is believed to be very much less than the figure above quoted.

The Barrière formation overlies the Fennell formation, but they are in juxtaposition along a fault contact near Louis creek. The drag of the Barrière quartzites, limestones, and schists against the Fennell greenstones is indicated on the map by the curving of the lines of regional strike. The relative movement along this fault and its effect in obscuring the lower parts of the Barrière formation are shown in the structural section on line A_1-B_2-B.

The Barrière River fault (Figure 19) separates this formation from the Fennell greenstones to the north.

Age and Correlation. No field evidence was obtained that would help to determine the age of this formation. The limestone members are all crystalline, and unlikely to yield fossils.

The Barrière formation was traced from Blucher Hall along the road to Adams lake, and was found to connect with the area of the Bastion schist of Daly at Skaam bay. This area is mapped provisionally by Daly as Bastion formation (pre-Beltian) for the reason that its lithology is similar to that of his type Bastion section 30 miles to the southeast[1]. On this account the present writer preferred not to use the same formational name for the series on the North Thompson.

Dawson, on the other hand, has included the Fennell and Barrière formations of the North Thompson valley and Daly's Bastion schists at Skaam bay in his Adams Lake series (Cambrian).[2] Daly restricts his Adams Lake greenstones ("effusive") to the upper or volcanic part of Dawson's Adams Lake series which overlies the Skaam Bay Bastion schists. These chlorite schists and greenstones of Daly's Adams Lake group do not, the writer believes, extend to the North Thompson map-area. They are probably cut off by the Barrière River fault and by the Baldie batholith. (Figure 19).

[1] Geol. Surv., Can,. Mem. 68, 1915, p. 20.
[2] Geol. Surv., Can., Maps Nos. 604 and 143 A.

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The relationships of the Badger Creek, Fennell, and Barrière formations to the formations of Dawson and Daly are represented in the following table:

G. M. Dawson	R. A. Daly	W. L. Uglow
Stratigraphy shown on the Kamloops and Shuswap sheets	Stratigraphy shown on the Shuswap Lake sheet	Stratigraphy shown on the North Thompson sheet
Cambrian: *Adams Lake series* — Upper portion: green schists of volcanic origin	Pre-Beltian: →Adams Lake greenstone..	→Not on North Thompson sheet (Cut off by Barrière River fault)
Cambrian: (Dawson maps this limestone belt as belonging to the Cache Creek group (Carboniferous))	Pre-Beltian: →Tshinakin limestone.....	→Not on North Thompson sheet (Cut off by Barrière River fault)
Cambrian: Middle portion: grey schists of sedimentary origin	Pre-Beltian: →Bastion schist.....	→Barrière formation
Cambrian: Lower portion: green schist and greenstone (volcanic)	→Not on Shuswap Lake sheet	→Fennell formation
Cambrian: *Niskonlith series*.....	→Not on Shuswap Lake sheet	→Badger Creek formation

Note: Correspondence of formations on the different sheets is indicated by double-headed arrows.

INTRUSIVE IGNEOUS ROCKS

Darlington Granodiorite

This is a medium- to coarse-grained, white to grey granitoid rock consisting chiefly of oligoclase, orthoclase, and hornblende. Much of the feldspar is clouded with alteration products, and the hornblende is partly altered to chlorite. Along its contacts the rock is locally gneissic.

Five dyke, sill, and border phases of this intrusive are met with. These are: (1) porphyritic hornblende granodiorite, in which phenocrysts of common hornblende up to 3 inches in length and ¾ inch in thickness are set in a fine-grained, greyish matrix of plagioclase and hornblende; (2) uralitized pyroxenite, which consists of a mosaic of large-sized grains of black uralite, containing small amounts of secondary intersertal calcite; (3) lenticular masses of quartz-orthoclase-muscovite pegmatite; (4) irregular-shaped masses of white to brown aplite; and (5) a border facies of fine-grained dark grey diorite.

With the exception of a fine-grained granitic sill and a pegmatite dyke, the exposures of this formation are confined to the west side of North Thompson river. The larger bodies occur as stocks to the west of Chu Chua and Barrière. These rocks intrude the Badger Creek, Fennell, and Barrière formations, but were not found cutting any other intrusive rock body. Their fabric is essentially granitoid, but towards their contacts a marked parallelism of hornblende crystal grains produces a noticeable gneissic appearance.

MICROPEGMATITE-PYROXENITE SILLS

This formation consists either of a composite sill or a differentiated sill. Lack of good exposures across the formation prevented exact determination.

The most westerly or upper part of the main sill is a coarse-grained, mottled grey rock which, under the microscope, is seen to be a granophyre, consisting of large, rectangular-shaped phenocrysts of orthoclase and acidic plagioclase, separated by important amounts of micropegmatite. Common green hornblende is an important accessory, and minor amounts of free quartz occur.

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The lower part of the sill or sills, which is exposed on the western flank of the crest of mount Baldie, is a brownish-weathering, medium-grained pyroxenite consisting almost entirely of greenish diallage with accessory magnetite.

The sills occur on the western flank of mount Baldie, interbedded with the Badger Creek and Fennell sediments and lavas. Outcrops of a similar rock occur on the plateau northeast of Chinook Cove just beyond the edge of the map, and are believed to be the southerly extension of these sills. In a deep ravine at the head of one of the westerly-flowing tributaries of Joseph creek, and near the crest of mount Baldie, these sills and associated sediments are seen to be truncated below by the Baldie batholith.

BIOTITE GRANDIORITE SILLS

Megascopically these sills are medium-grained, porphyritic, grey to brownish grey rocks consisting of glassy and buff-coloured feldspars, quartz, and hexagonal-shaped "books" of biotite. They were classified in the field as granodiorites. Phenocrysts of plagioclase up to one inch in length and width are common constituents and the reflection of light from their mirror-like faces is a striking field characteristic. These phenocrysts are poikilitically studded with grains of biotite and quartz.

A typical specimen of the rock proved under the microscope to be a porphyritic biotite quartz diorite with the following characteristics: large broken phenocrysts of andesine-oligoclase, showing marked albite twinning, zonary structure, and alteration in spots to zoisite and colourless mica; phenocrysts of biotite and quartz; and a groundmass or mosaic of quartz and twinned plagioclase.

Only two sills of this rock were found in the area, one about 2 miles south of the village of Mount Olie, and the other 1 mile west of the mouth of Fishtrap creek. They are placed together in the legend because of similar lithology. They stand in an almost vertical attitude, but their longitudinal extent was not determined. Their relationship to the other intrusive rocks of the district is not known.

BALDIE GRANITE

Megascopically this rock is coarse-grained, porphyritic to granitoid, and pale pink to light grey in colour. The chief constituents are clear glassy quartz, large cleavage grains and rectangular-shaped phenocrysts of pinkish feldspar, in which Carlsbad twinning is common, and minor amounts of biotite.

Under the microscope, the rock is seen to be an acidic quartz monzonite consisting of large grains of quartz, albite-oligoclase, and microperthite (the intergrowth being orthoclase and albite-oligoclase). The accessory constituents are chiefly biotite and magnetite.

This rock occurs in the form of a batholith whose western contact crosses the top of mount Baldie in a general north-south direction and swings away from the North Thompson valley in northeasterly and southeasterly directions. The batholith underlies a large stretch of country to the east, and is continuous with Dawson's Shuswap granite where it is exposed on Adams lake (Figure 19).

Where the western contact of the granite crosses the most southern tributary of Joseph creek, it plunges in a westerly direction at an angle varying from 35 degrees to 50 degrees, thus undercutting the adjacent members of the Badger Creek formation and their intercalated micropegmatite-pyroxenite sills. On the northwestern shore of Adams lake, the granite is in intrusive relations with Daly's Adams Lake greenstones, which are stratigraphically higher than the Barrière formation.

The relationship of this granite to the stocks of Darlington granodiorite on the west side of the North Thompson valley is not known, so that their respective positions in the legend are provisional.

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PETERSON CREEK SYENITE

In the field this rock is white to greyish white and porphyritic; and consists almost entirely of a network of lath-shaped crystals of feldspar with minor amounts of common hornblende, in a fine-grained, greyish matrix. The structure is markedly trachytic.

Under the microscope the rock is seen to be an alkaline syenite consisting largely of microcline, microperthite, and albite-oligoclase, with minor amounts of hornblende.

A stocklike mass of the syenite is found just south of Peterson creek at the western boundary of the map. It is intrusive into the stock of Darlington granodiorite with which it is in contact.

AGE OF INTRUSIVE ROCKS

No direct evidence was found in the map-area as to the time of intrusion of the igneous rocks. They are all probably younger than the rocks of the Barrière group, and older than the Eocene. The following points suggest that the intrusives are chronologically related to the Coast Range intrusion of late Jurassic times, rather than to the Precambrian.

Their general lack of foliation except in the vicinity of main contacts.

The lithological similarity of the Darlington granodiorite to the granodiorite of the Coast Range batholith.

The lithological similarity of the Baldie granite and granodiorite to the Nelson granodiorite, of which a series of stocks follows a general northwesterly course from near Nelson to the main line of the Canadian Pacific railway. The Baldie batholith may be another link in this chain of Mesozoic intrusions.

Tertiary

MIDDLE OR UPPER EOCENE—CHU CHUA FORMATION

This formation consists of a series of sedimentary beds ranging in composition from conglomerate through arkosic sandstone and highly feldspathic arkose to sandy shale, and containing coal seams. All the rocks are consolidated. The lowest member of the series is the basal conglomerate (or agglomerate). It consists of a heterogeneous mixture of rounded, sub-angular, and angular fragments of the older country rocks of the immediate vicinity. Some of these fragments are very large, whereas others resemble pebbles from stream gravels. The matrix of the fragments is a fine- to coarse-grained grit. Where the underlying rock is the Fennell greenstone, the larger part of the conglomerate is made up of large, irregular, talus-like pieces of that rock, associated with which are stream-rounded pebbles and boulders of granite and granodiorite. The basal portion of this conglomerate passes gradually by an increase in the quantity of fragments into the underlying rock, so that it is often difficult, if not impossible, to trace a definite contact surface between the two formations. The thickest section of the basal conglomerate exposed in any one place in the sheet is 150 feet (near Chu Chua station).

The intermediate and upper members of the formation consist of massive beds of coarse pebbly sandstone or fine-grained stratified conglomerate, and a considerable thickness of thin-bedded arkose and sandy shale. There is commonly an abrupt change in the grain in adjacent beds, and frequently a 3 to 4-inch layer shows fine-grained, sandy shale at its margins with fine-grained conglomerate at its centre. Several seams of sub-bituminous coal occur in the upper part of the formation, associated with the sandy shale and feldspathic sandstone.

The basal conglomerate is well consolidated and is grey to green in colour according to the relative abundance of the constituent fragments. The arkose and sandy shale are as a rule greyish white. Where these sediments are capped by Miocene lava flows, by which they have been considerably indurated, the shales are buff to brown, very markedly banded, and quite coherent.

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Distribution. The Chu Chua sediments were found in the following isolated localities in the northern part of the map-area:

The sides of the lower part of Newhykulston valley.
The southeast bank of Joseph creek, about 100 yards from the road bridge.
The gorge of Threemile creek, one-quarter of a mile above its junction with Lemieux creek.
Cliffs along the Canadian National railway for one mile north of Chu Chua station.
The gorge of Thuya creek, about 600 yards west of the road bridge.
The gorge of Darlington creek, about 300 yards upstream from the road bridge.
The east bank of North Thompson river at low-water level, one-quarter of a mile north of Chu Chua station.

Stratigraphy and Structure. The stratigraphy and structure of the Chu Chua formation are shown in the accompanying sections (Figures 12-16).

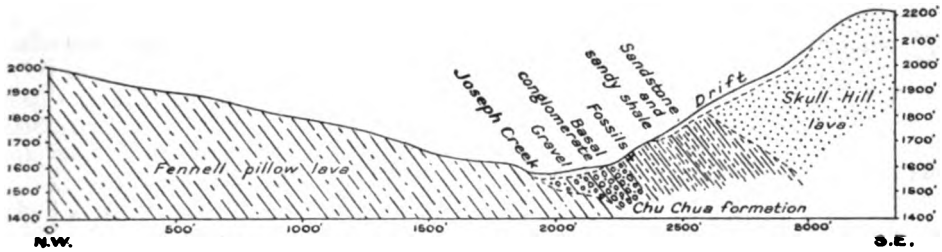

Figure 12. Vertical section across Joseph creek above road bridge, showing relations and structure of Fennell, Chu Chua, and Skull Hill formations.

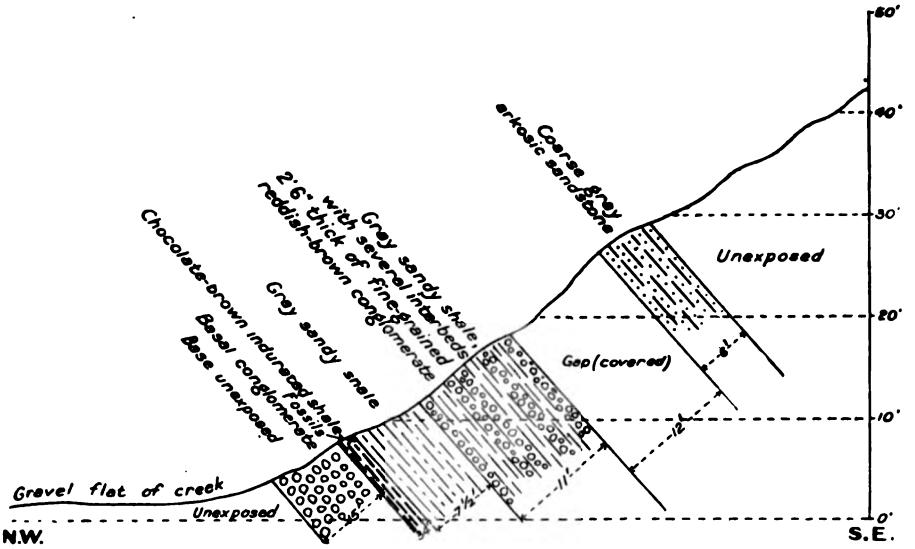

Figure 13. Detailed vertical section of the lower part of the Chu Chua formation shown in Figure 12.

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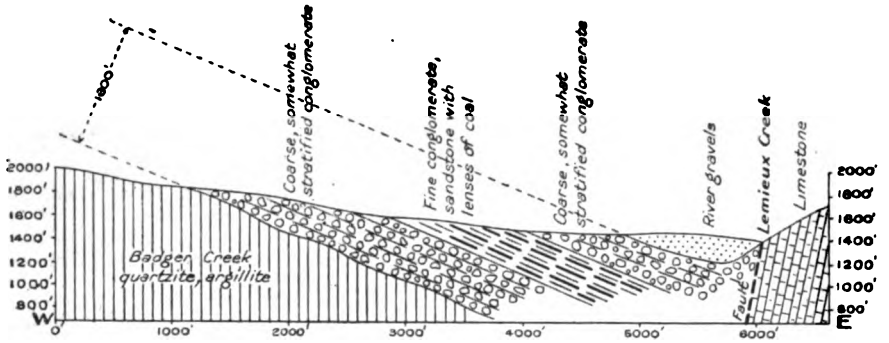

Figure 14. Vertical section along grade of Threemile creek, showing relation and structure of the Chu Chua formation.

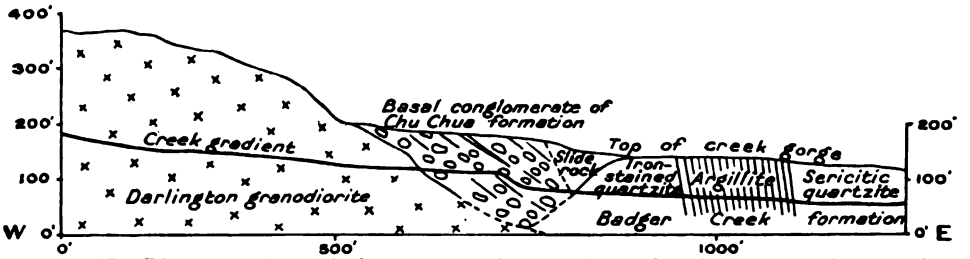

Figure 15. Diagrammatic vertical section showing relation of Chu Chua and Badger Creek formations and Darlington granodiorite, in Thuya Creek gorge.

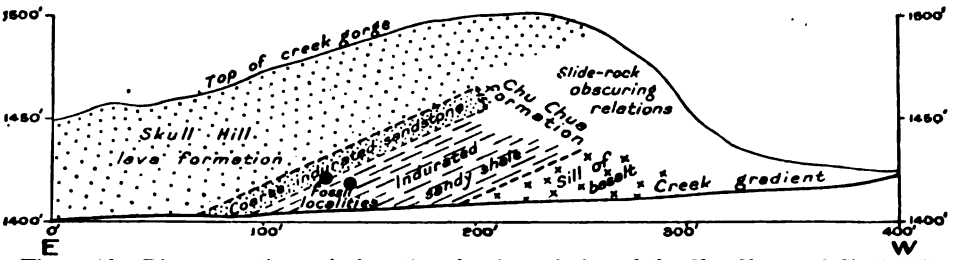

Figure 16. Diagrammatic vertical section showing relation of the Chu Chua and Skull Hill formations on south side of Darlington Creek gorge.

The following features are of particular interest.

The exposures are confined to the beds and lower slopes of North Thompson river and some of its tributary streams, and mostly occur below the 2,000-foot contour.

The longitudinal extent of the outcrops of the formation is in each case a short one. In the Newhykulston Creek area, for example, the only outcrop of these sediments is in the cut-banks of the stream valley. A low ridge, rising to a uniform height of a little over 2,000 feet (or 800 feet above the river), extends in northerly and southerly directions from the locality of the Chu Chua coal mine for distances of 2 miles and 1½ miles respectively. The topography of this ridge suggests that it is underlain by the Chu Chua formation, but, although it is traversed by several other stream valleys, no exposures of this formation were seen except those on Newhykulston creek.

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The basin of Chu Chua rocks exposed in Threemile creek may also continue longitudinally in northwest and southeast directions for 4 or 5 miles, but the only evidence in favour of this possibility is the topography.

The beds dip (uniformly) to the east and southeast at angles varying from 29 degrees to 50 degrees. The strike in all cases is parallel to the general trend of North Thompson valley.

The basal conglomerate has the appearance of a tumultuous deposit, or the consolidated product of a mixture of talus fragments and large stream boulders.

There is a total absence of limestone, and of well-assorted fragmental sediments. The shales are sandy and the sandstones are feldspathic.

The most continuous section of the Chu Chua formation is found along the sides of Newhykulston creek. Here the thickness represented between the lowest and highest seams of coal is 600 feet. The bottom of the basal conglomerate is at least 1,650 feet below the lowest seam of coal. A considerable thickness of Chu Chua sediments is believed to exist above the highest coal seam, but these are not exposed. Consequently, if there is no duplication of beds by strike faulting, the formation in this locality is probably 2,500 feet thick.

It is probable that the Chu Chua sediments extend underneath the lavas of the Skull Hill formation on the west side of North Thompson river between Chinook cove and Thuya creek, and have thus been protected from post-Miocene erosion.

The isolated patches of Chu Chua rocks are erosion remnants of a much more extensive formation which filled the Eocene North Thompson valley to a height of possibly 2,500 feet above its bed.

Age and Correlation. Suites of fossil flora were obtained from the localities indicated on the structural sections (Figures 12, 13, 16) and were submitted to Professor D. W. Berry, of Johns Hopkins University, for examination. Only a few specimens were obtained from Darlington creek, and these were not in very good condition. The Joseph Creek locality is abundantly fossiliferous, and the fossils are excellently preserved. The zone at this place is 3 to 4 feet thick, and fortunately it occurs less than 5 feet above the top of the basal conglomerate. The fossils from Newhykulston creek are from a shale at the top of the chief coal seam. The discoveries at these localities fix rather closely the age of the Chu Chua formation, from its base to the top of the main coal seam. Extracts from the reports by Professor Berry, establishing the age of the Chu Chua formation as Middle to Upper Eocene, are as follows:

Newhykulston Creek Collection

The following nine species were identified. The great bulk of the collection represents the sterile and fertile fronds of the fern genus *Woodwardia*. The presence of numerous fragments of dicotyledonous species on the backs of the thicker slabs of shale indicates that the number of such species would be greatly increased by further collecting.

1. *Woodwardi maxoni* Knowlton.
2. *Phragmites sp.*, Newberry, which is probably the same as *Phragmites alaskana* Heer.
3. *Poacites tenue-striatus* Heer.
4. *Musophyllum complicatum* Lesquereux (probably not a *Musophyllum*).
5. *Betula grandifolia* Ettinghausen.
6. *Corylus macquarrii* (Forbes) Heer.
7. *Grewia crenata* (Unger) Heer.
8. *Peterospermites alaskana* Knowlton.

Nos. 1, 2, 6, and 7 are Fort Union Forms. No. 4 is Green River. Nos. 2, 3, 5, 6, 7, and 8 are Kenai forms. The material is unquestionably of Eocene age and shows a mingling of Fort Union with the Arctic Tertiary flora which is now usually considered to be of Upper Eocene age. There is little resemblance to the Eocene floras of the John Bay basin in Oregon. Although the evidence is not conclusive, I would be inclined to consider the Chu Chua horizon as Middle or Upper Eocene and considerably younger than the so-called Canadian Upper Laramie, or Paskapoo.

9. *Taxodium occidentale* Newberry. Twigs of this species are not uncommon to the collection. The type was from the Fort Union, but is also recorded from the Lance, and from the Eocene of Mackenzie, Souris, Red Deer, and Blackwater rivers and Porcupine creek in British Columbia. Penhallow also recorded it from Quilchena, Tanquille, and Horsefly rivers, B.C., but his identifications are not very reliable.

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Joseph Creek Collection

This collection includes the following forms:

Acer macropterium Heer.
Acer fruits.
Alnus sp.
Alnus cones.
Betula sp.
Carpinus sp.
Comptonia, new species.
Corylus macquarrii Heer.
Diospyros sp.
Ginkgo adiantoides (Unger) Heer.
Glyptostrobus europaeus (Brongniart) Heer.
Leguminosites borealis Heer.
Hicoria, 2 species.
Liriodendron sp.
Myrica, new species.
Pinus trunculus Dawson (leaves and seeds).
Pinus, cone scales.
Phragmites alaskana Heer.
Populus, new species.
Querous grœnlandica Heer.
Querous, new species.
Sassafras selwynii Dawson.
Sequoia sp.
Taxites sp.
Taxodium dubium (Sternberg) Heer.
Taxodium occidentale Newberry.
Ulmus, 2 species.
Viburnum antiquum (Newberry) Hollick.
Equisetum similkamense Dawson.

This material contains one or two Paskapoo species, but it is in the main identical with the facies of the Kenai flora of Alaska. It shows but slight similarities to the flora of the Puget group, and I have no hesitation in saying that it is probably of Upper Eocene age.

Darlington Creek Collection

The identifiable forms comprise:

Corylus macquarrii Heer.
Pinus trunculus Dawson (both leaf fascicles and seeds).
Ulmus sp.

I regard this collection as of practically the same age as that at Joseph creek, namely Upper Eocene.

These collections of fossil flora establish the occurrence of a late Eocene coal-bearing formation in south-central British Columbia. This occurrence—the first authentic discovery of Eocene sediments in the Interior plateau—indicates some interesting physiographic relations (*See* pages 89 and 90).

Dawson classified the coal-bearing sediments of Newhykulston creek as Oligocene and correlated them with the Coldwater group.[1]

MIOCENE—SKULL HILL FORMATION

This formation consists of a series of volcanic flows, minor amounts of flow breccias, and a few sills in the Chu Chua formation. Microscopic examinations of thin sections prove the flows and sills to be very constant in mineralogical composition and petrographic type. They are black, brown, and greyish-green, the black and brown predominating. The lavas are mostly highly amygdaloidal, the amygdules consisting of chalcedony, agate, hyalite, zeolites, calcite, serpentine, and some native copper.

Hornblende-andesite is the common type. Its characteristics are so marked that they may be used as a basis to differentiate the Skull Hill lavas from other flows in this area. The groundmass consists of a fine to medium-grained, felted mass of plagioclase laths of the composition of andesine-labradorite with interstitial augite

[1] Geol. Surv., Can., Ann. Rept., vol. VII, N.S., 1894, p. 229 B.

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and hornblende. Its structure varies from pilotaxitic to hyalopilitic. Fluxion structure is not very marked except in the vicinity of the phenocrysts. These are predominantly basaltic hornblende whose outlines are usually six-sided. The peripheries of the phenocrysts consist of a mass of grains of a black opaque mineral, probably magnetite, which appears to be the result of interaction between the hornblende and the surrounding magma. All stages from incipient to complete transformation of the basaltic hornblende to magnetite may be seen in the sections. Other phenocrysts, not so commonly present, are augite and andesine-labradorite. Hourglass structure occurs in some of the augite, and twinning is not unusual. Zonary structure is very common in the plagioclase phenocrysts. Magnetite is a fairly abundant accessory constituent.

The amygdaloidal parts of the formation are mostly much decomposed, especially where they have been soaked by percolating water from the artesian flow and the streams which traverse them.

Distribution. The formation occurs in three localities within the map-area:

On Skull hill, where it produces the mesa-like top of the mountain.

Along the west bank of the river commencing 6 miles north of Peterson creek and continuing to a point opposite Chu Chua. In this reach it constitutes a rock-defended terrace, fringing the base of the main valley slopes.

As a capping to the Chu Chua formation at the northeast end of Dunn lake.

More extensive exposures are found in the region of Clearwater river, but this area was not studied carefully during the season, and the details of the occurrence were not noted.

Structure. The andesites of Skull hill are in a nearly horizontal attitude. The lower part of them, including their contact with the underlying formations, is obscured by talus and glacial drift, so that the greatest exposed thickness is 1,100 feet. It is not known whether any part of the Chu Chua formation is buried beneath these flows, or whether they lie directly on the Fennell greenstones and green schists.

In the Dunn Lake area only the upper part of the lavas is exposed, but 400 feet is believed to be a conservative estimate of their thickness. The flows appear to dip to the southeast less steeply than the underlying Chu Chua sediments, but this point could not be definitely determined.

In the area on the west side of North Thompson river the rocks of the Skull Hill formation are largely concealed under the glacial overburden. Sections of them are obtained along the gorges of the various streams running easterly. Exposures are, however, quite abundant locally on both sides of the main road from 1½ to 3 miles north of Chinook Cove.

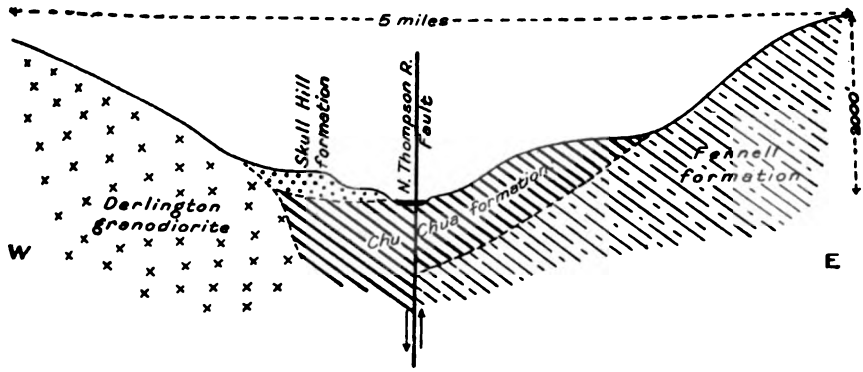

Figure 17. Generalized cross-section showing the faulting of the Tertiary formations in North Thompson valley. Vertical scale greatly exaggerated.

For 7½ miles along this side of the river, the rock terrace continues, and on it some of the richest agricultural land of the district is located. This terrace is ar

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erosion remnant of the lava flood-plain, which formerly filled the North Thompson valley to a height varying from 600 to 2,000 feet above the present river grade.

In many places these andesites are notably sliced or traversed by a series of closely-spaced parallel fractures that correspond in strike to the trend of the main trench. These fractures give the rock the appearance of a schist, but there is no evidence of recrystallization or of the development of platy minerals.

The strip of Skull Hill lava on the west side of the main river trench and the stratigraphically lower Chu Chua sediments on the east side, just opposite, suggest the occurrence of post-Skull Hill faulting parallel to the trend of the trench along which the western side has dropped relatively to the eastern side (Figure 17). The fracturing and slicing mentioned in the previous paragraph are believed to be a result of this faulting.

Age and Correlation. No sediments older than the Pleistocene and overlying the lavas were found within the sheet. The Skull Hill formation is, therefore, only provisionally referred to the Miocene.

Quaternary

PLEISTOCENE

Glacial Drift. A large part of the area mapped, particularly the lower slopes of the valley and the uplands of the plateau, is covered by glacial drift. Glacial striæ were found on some of the rocky knolls on the plateau and D. A. Nichols found well-marked striæ on Granite mountain, northeast of the geological map (No. 1945) at an altitude of 7,500 feet.

RECENT

White Silts. Terraces of the White Silts (of Dawson) occur in many parts of North Thompson valley and on its main tributaries. They are found at altitudes up to 2,000 feet. As stated by Dawson[1] the White Silts were probably a lacustrine deposit of the finer parts of the material made available just after the last glacial retreat.

River Deposits. These consist of stratified stream and river gravels and silts occurring on the valley flats and as terraces rising to over 500 feet above the level of North Thompson river.

Lava. A highly vesicular andesitic lava, probably of post-Pleistocene age, is found in the canyon of Mann creek and about 1½ miles above its mouth. This district is outside the limits of the present sheet and it was not examined in detail. A section of the occurrence is given in Figure 18.

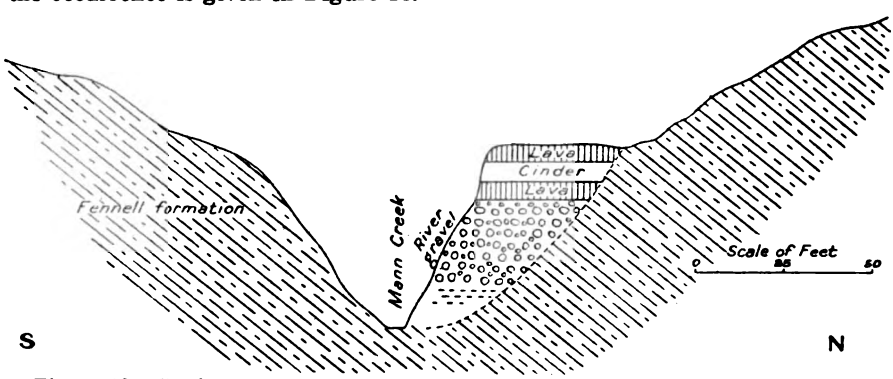

Figure 18. Section showing mode of occurrence of post-Pleistocene lava covering Recent gravels in gorge of Mann creek.

This lava, of which two 10-foot flows, exposed in the cliff face, are separated by 10 feet of cinder, covers unconsolidated, assorted coarse stream gravel. The gorge itself is of post-glacial age.

[1] Geol. Surv., Can., Ann. Rept., vol. VII, N.S., 1894, pp. 283-291 B.

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DEVELOPMENT OF NORTH THOMPSON VALLEY AND SUMMARY OF THE GEOLOGICAL HISTORY

The following inferences are based on the field facts obtained within the North Thompson map-area and do not necessarily apply to the Interior plateau as a whole. The country mapped is entirely within the drainage basin of North Thompson river—it is indeed confined to the immediate slopes of the valley—and some rather interesting facts were obtained relating to the physiographic history of this particular trench.

Owing to the absence of any recognized sediments of the Mesozoic era, and possibly of the Palæozoic era, the geological history of this area in pre-Tertiary times is difficult, if not impossible, to decipher. At the beginning of the Tertiary period, the rocks had already been at least once severely faulted, folded, rendered schistose, and intruded by magmas of the batholithic, sill, and stock types. In general, the strike of these pre-Tertiary rocks is northwest, indicating a control by the forces which developed the Cordilleran structure.

The panorama obtained from an altitude of about 4,000 feet reveals two main facts: (1) The uplands between 3,500 and 4,000 feet show a gently undulating type of topography with a very even skyline. This continues for many miles in all directions, and presents the appearance of an uplifted peneplain. Above this peneplain, there are several isolated peaks and ridges, some of which rise to altitudes of 8,600 feet. Examples of these are mount Baldie (7,500 feet), Dunn peaks (8,600 feet), and Poison hill (5,370 feet) (Plate III A). They are evidently monadnocks. (2) Commencing 3 to 5 miles on either side of the present North Thompson river, this peneplain gently slopes towards the axis of the valley. If the present river trench were obliterated these two opposite upland slopes would smoothly curve downwards and would unite over the trench at a height of perhaps 2,000 feet above the bottom of the present valley. This exceedingly flat northerly trending depression in the peneplain is believed to represent the late Cretaceous valley of the ancestral North Thompson river. Since this valley is preserved in a state of physiographic old age, it was, probably, the course of the old North Thompson as it meandered with a very low gradient over the peneplained southern interior in late Cretaceous time, previous to the Laramide revolution. It was evidently the master drainage course in those times, and the bottom of its valley was the lowest point of that late Cretaceous topography. The depth of erosion since that time would, therefore, be represented by about 2,000 feet, or the distance between the bottoms of the Cretaceous and present-day North Thompson valleys.

It is interesting to note that the present North Thompson river which, as already stated, inherits the valley of its ancestor, in many places crosses the prevailing Cordilleran structure.

The sediments of the Middle or Upper Eocene (Chu Chua formation) are confined to the lower parts of the present valley. They are found below the present water level and to a height of 800 feet above it, but higher parts of them may have been removed during the post-Eocene or post-Miocene erosion cycle. The evidence is, therefore, conclusive that the depth of the North Thompson trench in Middle or late Eocene times was approximately the same as now. Between the time of the uplifting of the Cretaceous peneplain and of the deposition of the Chu Chua formation, the North Thompson valley was eroded to a depth of probably more than 2,000 feet.

The Eocene sediments are a regularly bedded series of coarse to medium-grained fragmental rocks, in which the arkose and greywacke types prevail. These indicate rapid erosion of the lands from which they were derived. The occurrence of these Chu Chua beds on both walls of the present trench and throughout a considerable distance in northerly and southerly directions, the general lack of crossbedding, and the presence of many shale horizons suggest that they are of lacustrine origin. The flooding of a large, youthful valley in this manner accounts for the character of the

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Chu Chua basal conglomerate, which, as mentioned above, resembles a consolidated mass of talus and coarse stream gravel, such as was probably lying in the lower parts of the old North Thompson at the time of the formation of the lake. Repeated fillings of the lake basin, at several stages of its development, by fragmental sediments, and the growth of luxuriant and somewhat modern vegetation account for the occurrence of the coal seams.

The angular discordance which is evident in places between the beds of the Chu Chua formation and the overlying Miocene lavas points to a minor disturbance probably in Oligocene times. The Chu Chua formation seems to have been block-faulted along lines parallel to the general trend of the North Thompson trench. The beds in the various blocks dip 20 degrees to 40 degrees to the east.

Erosion during the Oligocene bevelled the upturned edges of the Chu Chua sediments.

During the Miocene great subaerial flows of andesitic lava spread over the country. Outside the boundaries of the North Thompson Valley sheet, these lava flows buried the uplifted peneplain; within the North Thompson valley they capped the Chu Chua sediments to a thickness of upwards of 1,100 feet, and filled the river valley from side to side. The drainage of the river was consequently blocked and locally altered. The lavas flooded the Clearwater valley to the north, but post-Miocene stream-cutting has removed part of them and has exposed cliffs, 100 feet high, of highly decomposed and bleached granite. These exposures afford very picturesque evidence of the depth and character of early Tertiary weathering.

Diastrophism—following the extrusion of the Miocene lava—raised, tilted, and faulted the flows and underlying rocks within North Thompson valley. The effects were mostly those of faulting (Figure 17). Dawson[1] describes the occurrence of tilted lava flows on parts of the plateau.

In Pliocene times, following the post-Miocene diastrophism, a long period of erosion ensued until the upturned edges of the lava flows were bevelled, and until the river had re-cut its channel down into the Chu Chua sediments.

The Pleistocene ice-cap which covered this part of British Columbia to a considerable depth glaciated and grooved the rocky hills and slopes and scoured and deepened the valley.

On the retreat of the ice great quantities of loose rock were supplied to the river, which spread the material across its valley in a great valley train. Subsidence of the land followed and great thicknesses of white silts probably of marine deposition covered the drift and glacio-fluvial gravels to depths of several hundred feet.

Post-Pleistocene emergence rejuvenated the river and caused it to re-cut its channel in the same course, leaving the glacio-fluvial gravels and white silts as terraces perched on the valley sides at heights up to 1,000 feet above the bottom. The North Thompson was again entrenched to a depth approximately the same as that of early Eocene time.

Lavas of unknown extent were extruded during Recent time.

GENERAL STRUCTURE OF THE BONAPARTE LAKE-CHU CHUA-ADAMS LAKE REGION

A sketch showing the relation of the geology of the map-area to that of the adjoining districts to the east and west is shown in Figure 19. On it the following relations are illustrated:

The North Thompson map-area and the North Thompson trench lie between two batholiths: that of the Darlington granodiorite and its associated intrusives to the west, and that of the Baldie granite to the east. The difficulty of working out a correlation of the North Thompson rocks becomes evident, when it is realized that they are a much metamorphosed part of the batholithic roof.

[1] Bull. Geol. Soc. Am., vol. 12, 1901, p. 81.

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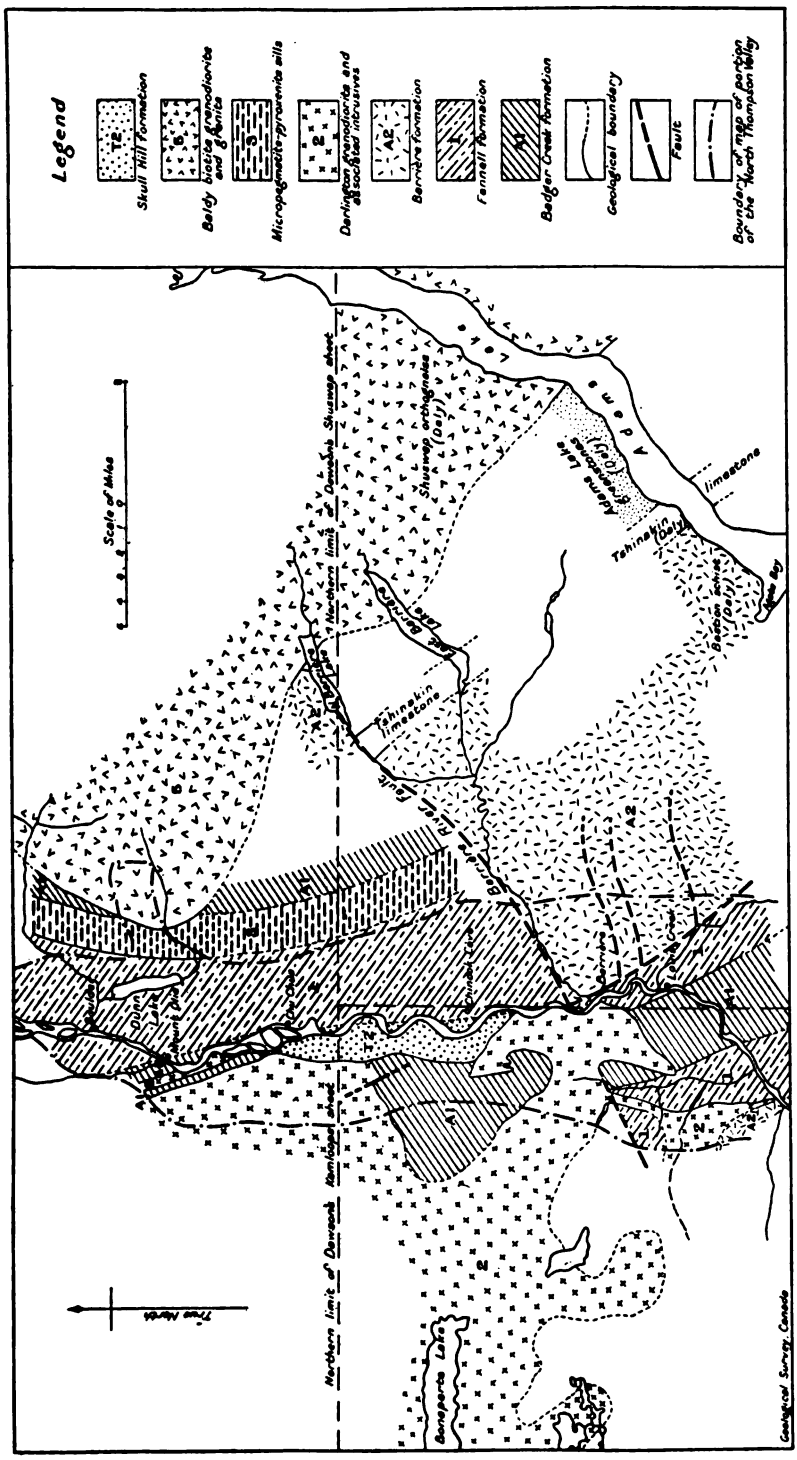

Figure 19. Diagram showing general geological structure of North Thompson valley and adjacent districts and relationship between the areal geology of G. M. Dawson and R. A. Daly and that of the map-area of a part of North Thompson valley.

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The Baldie granite of this map-area is seen to be continuous with the Shuswap granite and orthogneiss of Adams lake which Dawson and Daly have classeified as Archæan.

Daly's Tshinakin limestone continues with few interruptions as a very noticeable white ridge from the northwest shore of Adams lake to North Barrière river. Here it stops abruptly, as shown. His Adams Lake greenstones are similarly cut off. The northwest shore of North Barrière lake consists of the Barrière formation.

The areal connexion of the Barrière formation with Daly's Bastion schists of Skaam bay is shown.

The position of the Barrière River fault zone crossing the Cordilleran trend and truncating the Badger Creek, Fennell, Barrière, Tshinakin, and Adams Lake formations is clearly illustrated. The fault zone was not found to cut the batholith.

ECONOMIC GEOLOGY

COAL

Coal has been known for a great many years to occur on the lands of the Indian reservation near Chu Chua. The exact locality of the occurrence is in the gorge of Newhykulston (Coal) creek three-quarters of a mile above its mouth. The exposures are at altitudes of 1,400 to 1,500 feet. A road running down the valley for 1,200 yards to a siding on the Canadian National railway makes the coal readily accessible.

Stratigraphy and Structure

The coal measures are of Middle or Upper Eocene age as determined from the flora found at the top of the main seams. A detailed section of the coal measures is given below. The beds strike north 20 degrees east and dip 23 degrees to 25 degrees southeast (Figure 20 A and B).

Coal Seams

There are three main seams which are referred to as the Gray, the Smith (A and B), and the Thomas (A and B) seams. Several other thin seams are shown on Figure 20 A and B as the A, B, C, D, E, F, G, H, J seams. For the thickness and physical characters of the minor seams, attention is directed to the stratigraphical section.

The coal is usually frozen to the bands of sandstone that occur within the main boundaries of the seam, but it breaks free from the capping and floor.

The capping is rigid, and requires very little timbering.

There is an absence of fire-clay at the base of the coal seams.

The seams thin and thicken, roll, split, and unite in short distances laterally. Such an occurrence makes an estimate of reserves exceedingly difficult to make.

Thomas Seam. Until the end of the summer of 1921, practically all the development had been confined to this horizon. It is a double seam, the upper part being the A, and the lower the B. In the outcrop along the side hill, these two parts of the seam are separated by 9 to 10 feet of arkosic sandstone and arenaceous shale. At the time of the writer's examination, they were seen to be not more than 3 feet apart in the bottom of the slope. At a lower level they may unite and form a seam 4 to 5 feet thick.

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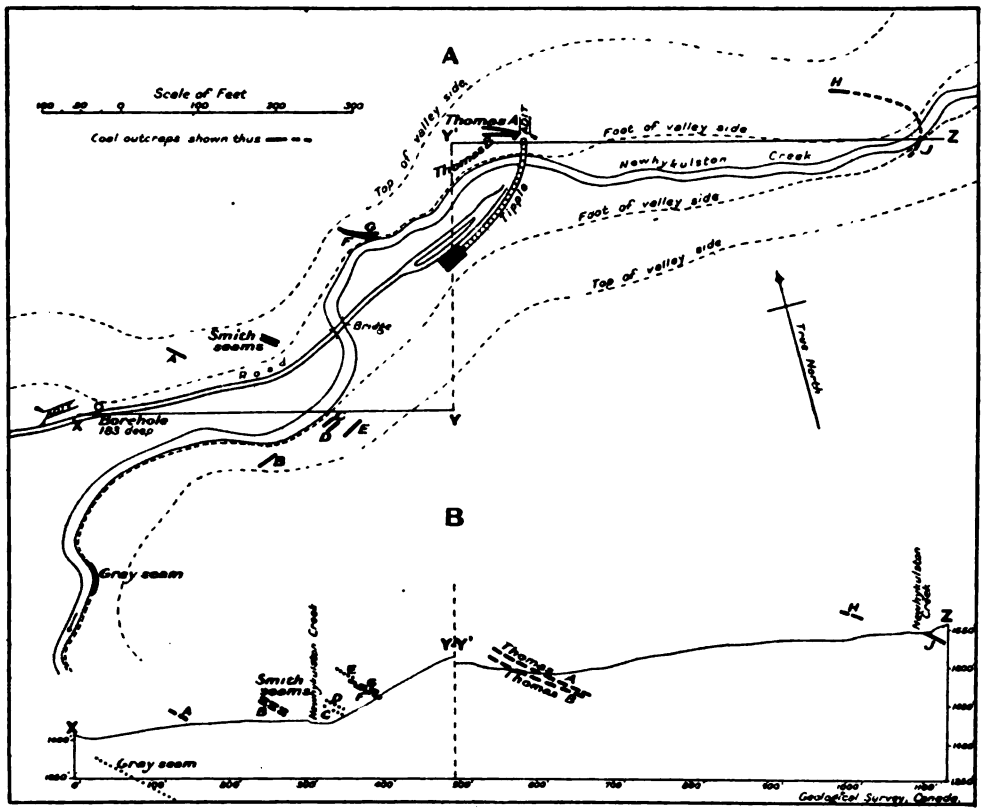

Figure 20. A. Plan showing outcrops of coal on the property of the Chu Chua Coal Company. B. Representation of outcrops of coal seams in a vertical plane along lines XY-Y'Z. Coal seam outcropping on the line of section is shown in solid line; coal seams on north side of line are shown by broken line; and coal seams on south side of line are shown by dotted line.

The two parts of this seam vary in physical character and thickness within very short distances along the beds. The following sections reveal in detail the nature of the seams:

(1)

Sandstone roof
12 inches hard, black, lustrous coal (streak brown)
1½ inches sandy shale
1 inch hard, lustrous coal
3 inches grey sandstone
10 inches hard, black, lustrous coal (streak brown)
2½ inches sandstone
7 inches coal
2 feet sandstone floor
Total coal: 30 inches.

(2)

Sandstone roof
8 inches hard, massive, lustrous coal
2 inches shale
1½ inches coal
1 inch shale
7½ inches coal
2 inches sandy shale
5 inches coal
Sandstone (smooth floor)
Total coal: 22 inches.

(3)

Sandstone roof
30 inches coal—Thomas A seam
36 inches sandstone
30 inches clean coal—Thomas B seam

(1) Vertical section of Thomas B seam on south wall at the bottom of main slope.
(2) Vertical section of Thomas A seam on north face, lower level.
(3) Vertical section of Thomas A and B seams, 20 feet north of No. 1 chute, lower level.

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Smith Seam. This is also a double seam and is exposed in a short slope. A section down the slope is given in Figure 21.

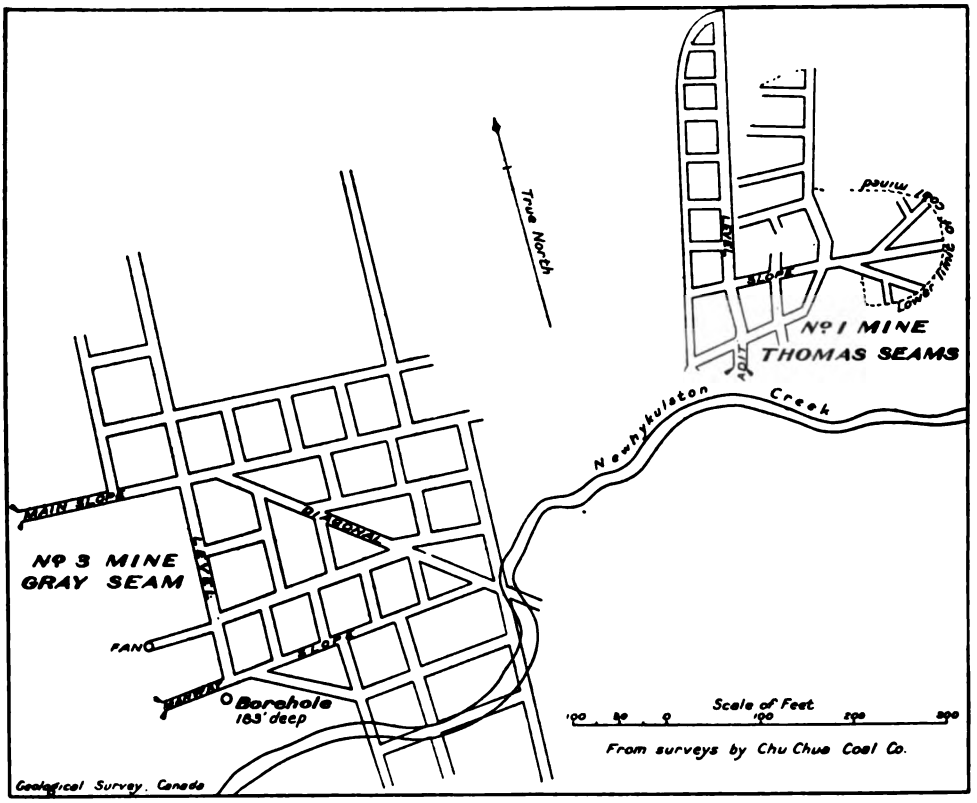

Figure 21. Plan of underground workings of Chu Chua Coal Company.

The detailed stratigraphic section at the portal of this slope is as follows:

Massive pebbly sandstone capping.
18 inches to 20 inches hard, thinly laminated, fairly clean coal.
20 inches to 48 inches hard, massive grey sandstone.
6 inches shale with coaly partings.
10 inches coal with shale partings.
Fissile grey (arenaceous) shale floor.

Gray Seam. This is the lowest coal so far discovered in the measures. It was uncovered at the time of the stream freshet in June, 1921, by the sapping of a thick mantle of glacial drift. At the suggestion of the writer a small excavation was made at this point and revealed the structure and relations shown in Figure 22. This outcrop was much weathered and it was difficult to determine how much clean coal was in the seam.

Physical Characteristics and Grade of Coal. The coal is a hard, black, lustrous, thinly laminated variety with a dark brown streak. It is very friable but it does not readily blacken the fingers. The seams lack the perpendicular prismatic jointing so characteristic of bituminous coal, but possess instead the thinly laminated structure found in lignites. The coal weathers rapidly and becomes coated with a yellowish-white alteration product. It burns readily with a long yellow flame, and it is said to be an excellent steam-producing fuel.

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Small lenses, blebs, and irregular-shaped masses of a semi-transparent, amber-yellow material occur within the seams. This is the fossilized form of some of the resins of the coal-forming trees. As a result of the biochemical and dynamochemical changes which took place during the formation of the coal, the woody parts of the seam were much carbonized and fractured, whereas the resins resisted the biochemical changes to the last.[1] Being plastic, the fossilized resins accommodated themselves by

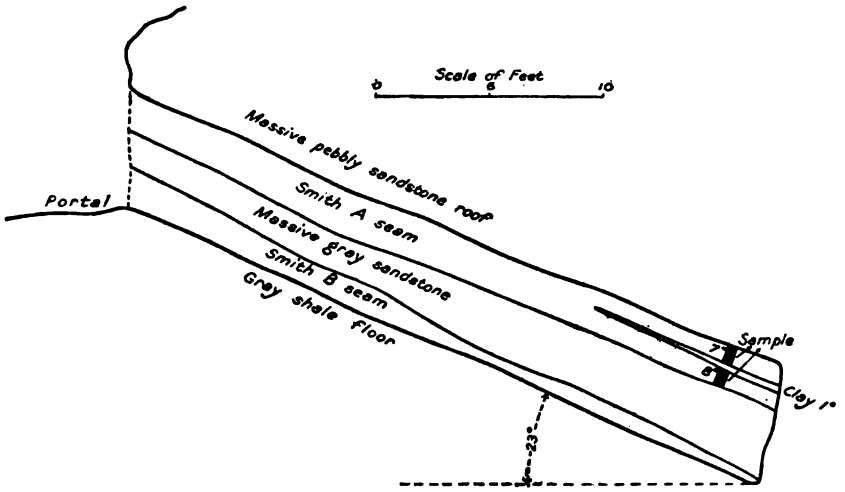

Figure 22. Vertical section through slope on Smith seam, Chu Chua Coal Company.

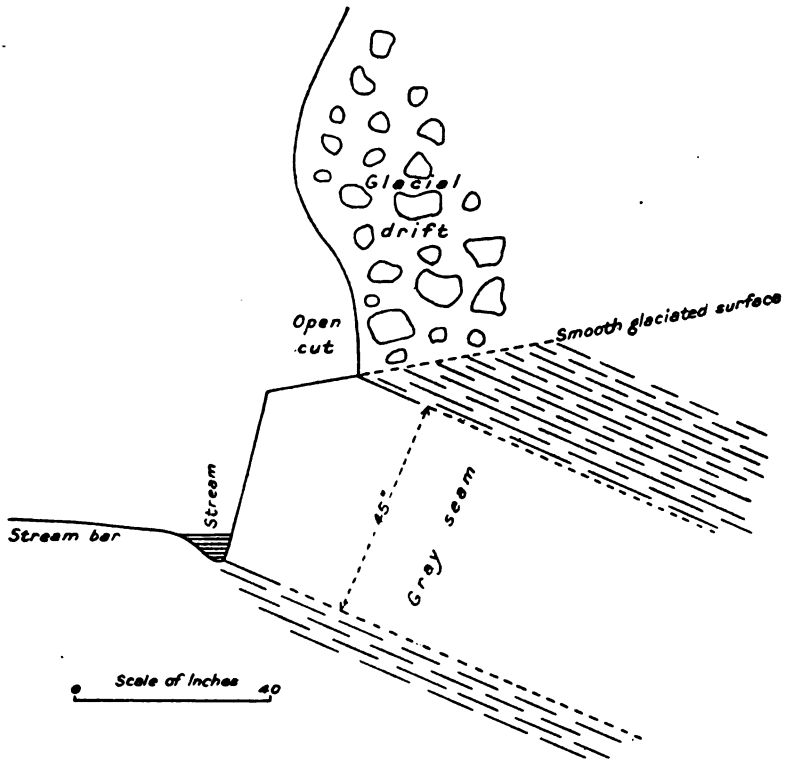

Figure 23. Vertical section parallel to dip on Gray seam, Chu Chua Coal Company.

[1]U.S. Geol. Surv., Prof. Paper 85, 1914.

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flow to the shapes of the fractures in the coal, and now they occur in cracks and cavities of all shapes; and in places they present the appearance of having replaced the coal.

Four samples of coal from the seams were submitted to the Mines Branch, Ottawa, for analysis. The samples were analysed as received (R) and as dried at 105 degrees C. (D). The results are given herewith:

—	(1)		(2)	
	R	*D*	*R*	*D*
	Per cent	Per cent	Per cent	Per cent
Moisture	4·0	.....	3·7	.....
Ash	24·0	25·0	37·3	38·8
Volatile matter	36·1	37·6	29·4	30·5
Fixed carbon	35·9	37·4	29·6	30·7
Fuel ratio	0·99	0·99	1·01	1·01
	Sample made poor coke in very small lumps		Sample agglomerates	
British thermal units	10,290	10,700	8,230	8,550

—	(3)		(4)	
	R	*D*	*R*	*D*
	Per cent	Per cent	Per cent	Per cent
Moisture	3·6	.....	4·0	.....
Ash	13·8	14·3	22·1	23·0
Volatile matter	37·9	39·3	37·9	39·5
Fixed carbon	44·7	46·4	36·0	37·5
Fuel ratio	1·15	1·15	0·95	0·95
	Small lump fair coke		Small lump poor coke	
British thermal units	12,040	12,490	10,780	11,230

(1) Sample represents a channel of 15 inches in length across the Smith A seam, at a point 30 feet down the slope from the portal (Figure 21).

(2) Sample represents a channel 41 inches in length across the Gray seam. It includes 4 inches of coal shale, 8 to 10 inches of hard lustrous coal, 1 inch of clay, followed by weathered soft, shaly coal to the bottom.

(3) Selected sample of the best grade of coal from the upper 8-inch part of the Thomas A seam.

(4) Selected sample of the best grade of coal from the Thomas B seam.

These results show that the coal should be classified as low grade, low rank bituminous, or low grade, high rank sub-bituminous.[1] The fuel ratio is that of a low rank bituminous coal; the moisture content suggests a high rank bituminous; the large amount of ash makes it a low grade coal; and the lack of prismatic structure and the tendency to split into sheets parallel to the bedding indicate a sub-bituminous coal.

It seems probable that the original lignitic coal seams of this district were raised to sub-bituminous rank by thermochemical means; the heat having been supplied by Miocene lavas which, it is believed, formerly covered the coal measures. These lavas have since been completely removed by erosion.

Development. During the summer of 1921 development was confined to the Thomas seams, on which there was an adit 125 feet long, with workings which continued down the slope for about 200 feet. About twenty-five men were being employed by the Chu Chua Coal Company, the only operators. During the winter of 1921-22 underground development was carried out on the Gray seam. A short slope on the Smith seams, driven several years ago, was abandoned (Figure 20 B).

[1] U.S. Geol. Surv., Prof. Paper, 100-A, 1917, p. 3.

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Production. During September, 1921, this property produced from one to two cars of coal a week. Towards the end of the year the Chu Chua Coal Company reported a production of about 40 tons a day.

Extent of Basin. As stated above in the discussion of the Chu Chua formation, owing to lack of exposures very little information is available regarding the longitudinal extent of the coal measures. They may extend 5 to 6 miles in a north-south direction underneath the low ridge that parallels the base of Chinook mountains.

Down the dip, the seams will, of course, be cut off where they overlap the surface of the Fennell greenstones, which represent the old shore-line of the lake.

In the detailed stratigraphic section of the coal measures in Newhykulston creek there is shown an interval of about 1,500 feet between the Gray seam and the basal conglomerate. In this interval, other seams of commercial value may occur.

The most important point to be determined by the present operations is, however, the longitudinal extent of the basin and this can be done only by intelligent drilling.

Coal may also be found in other parts of the North Thompson or tributary valleys where erosive agencies have not entirely removed the rocks of the Chu Chua formation.

Section of Chu Chua Formation on Newhykulston Creek

	Ft.	In.	
South Side of Creek—			
Black carbonaceous shale		3	
Coarse grey sandstone with black shale parting	5	0	
Coal shale		6	
Crossbedded shaly sandstone	1	6	
Coarse grey sandstone	4	0	
Grey shale	1	6	
Coarse grey sandstone, massive	3	0	
Grey shale and sandstone, interbedded	3	0	
Hard, massive, fine-grained grey sandstone	2	0	
Grey and black sandstone and shale interbedded	9	0	
Black carbonaceous shale		9	
Grey sandstone with shale partings	1	9	
Grey shale		6	
Black carbonaceous shale		6	
Coal, fissile, clean—J seam		7	
Shaly sandstone		6	
Black carbonaceous shale		6	
Massive grey sandstone	1	6	
Gap	200±		
North Side of Creek—			
Grey sandy shale, weathers blotched white	8	0	
Fine-grained grey sandstone	2	0	
Grey, sandy shale	4	0	
Grey shale, with sandstone at top, and 6 inches carbonaceous shale at bottom	2	0	
Grey shale, carbonaceous at base, sandy at top	1	3	
Loose sandstone with 6 inches of fine conglomerate in centre	2	0	
Grey, flaggy shale, weathers blotched		8	
Massive, fine-grained grey sandstone	1	9	
Fissile, carbonaceous shale		12	
Massive, fine-grained grey sandstone		12	
Fissile grey shale		8	
Coal and shale, interbedded		4	
Brownish-grey, thinly laminated, fissile shale, fossiliferous		6	
Coal, clean		8	Thomas A seam
Coal shale with 1-inch to 2-inch seams of coal		12	Thomas A seam
Coal, clean		11	Thomas A seam
Brown carbonaceous shale		4	
Coal shale with 2 inches of *coal*		7	
Grey, friable, thin-bedded shale	10	0	
Coal shale		6	Thomas B seam
Coal	1	4	Thomas B seam
Gap—Buried	20	0	
Coarse sandstone and fine pebble conglomerate	10	0	
Grey sandy shale		12	
Fine conglomerate	1	6	
Coarse grey sandstone	7	0	
Gap—buried	30	0	
Massive, coarse grey sandstone	10	0	

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Section of Chu Chua Formation on Newhykulston Creek—Continued

	Ft.	In.	
North Side of Creek—Con.			
Grey fissile shale	5	0	
Massive grey sandstone bed	2	5	
Fissile grey shale		4	
Shaly *coal*, weathered—G seam		12	
Massive grey sandstone	3	0	
Fissile grey shale		9	
Coal, thinly laminated, weathered—F seam		11	
Hard, fine-grained, greenish grey clayey sandstone	1	3	
Fissile carbonaceous shale	2	0	
Grey sandy shale	1	10	
Hard, massive grey sandstone		12	
Fine-grained crossbedded pebble conglomerate	10	0	
Coarse, grey, crossbedded sandstone	12	0	
Grey flaggy shale	5	0	
South Side of Creek—			
Black carbonaceous shale	1	6	
Grey sandstone	2	0	
Grey sandy shale		12	
Coal shale } D		3	
Coal, thinly laminated } seam		9	
Grey, massive sandstone with 6 inches shaly sandstone at top	6	0	
Gap—Buried	3	6	
Coal } C		6	
Coal shale } seam		12	
Gap—Buried	20		
Shaly *coal*—Upper Smith seam	1	10	
Sandy shale		12	
Hard, grey, massive sandstone	3		
Shaly *coal*		4	Lower
Coal, brittle, thinly laminated rusty weathering		12	Smith
Shaly *coal*		4	seam
Grey fissile shale		6	
Hard, buff, massive sandstone	2	6	
Grey fissile shale		12	
Buff sandstone with sandy shale	4	0	
Massive grey sandstone	2	7	
Black carbonaceous shale		5	
Shaly sandstone		12	
Coal shale		4	
Grey sandy shale	1	3	
Carbonaceous shale	3	8	
Coarse, pebbly grey sandstone, massive	16	0	
Grey sandstone	2	0	
Conglomerate		12	
Black carbonaceous shale		7	
Gap—Buried	4	6	
Shaly sandstone	2	0	
Shale		12	
North Side of Creek—			
Coarse, pebbly grey sandstone with three interbeds of conglomerate	4	6	
Gap—Buried	6	6	
Coarse, pebbly sandstone with few black and grey shale partings	6	6	
Grey sandy shale		12	
Coal		1	
Carbonaceous shale } A-seam		3	
Coal		4	
Buff sandy shale		6	
Gap—Buried	10		
Massive grey sandstone, coarse to fine	12	6	
Grey sandstone with thin beds of conglomerate	2	6	
Gap—Buried	45		
South Side of Creek—			
Coal—Grey seam	3	9	
Gap—Buried	1,500±		
Basal conglomerate	150+		

Base unexposed.

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Gold Hill

The Gold Hill and Gold Hill Fraction are located on the southern and south-eastern slopes of Gold Hill ridge. The chief mineralized zone, which is described below, occurs at altitudes varying from 2,720 feet to 3,425 feet. It is reached by a trail about 1½ miles long which leaves the main road three-quarters of a mile south of the south end of Dunn lake. The nearest railway station is Chu Chua, 5 miles from the lower end of the trail.

The property is recorded in the names of George Fennell and Henry Skoney, of Chu Chua.

The country rock is the greenstone pillow lava of the Fennell formation. This rock is traversed in a general east-west direction by shear zones which have been altered to cream and buff-coloured masses of siliceous ferrodolomite, through which ramify veinlets and irregular masses of white quartz. In many cases the quartz is broken and the fragments are cemented by ferrodolomite. The contacts between the ferrodolomite and greenstone are, as a rule, transitional. The width of the main ferrodolomite zone varies up to 20 feet. The quartz stringers carry appreciable amounts of fine and medium-grained galena, associated with less amounts of chalcopyrite, pyrite, and sphalerite. Free gold occurs scattered through these veinlets, and seems to be associated with the galena. Individual grains of gold were seen as large as pin heads and a few the size of small peas. Much invisible gold is scattered through the quartz and also in the ferrodolomite. Small pieces of rusty quartz when panned produce a very decided yellow streak, due to fine particles of gold. The quartz is rather intimately impregnated with small grains, and traversed by tiny veinlets of ankerite. The easy cleavage of this mineral makes the quartz very friable, and produces by its oxidation a buff to brown colour in the zone. Limonite is abundant as an oxidation product of the ankerite, and malachite and azurite as alteration products of the chalcopyrite.

Very little work has been done to determine the extent and value of the ferrodolomite zone. At least eight trenches and shallow open-cuts intersect the mineralized zone, and these are spaced through an horizontal length of at least 1,500 feet. It is not certain that the mineralization extends for this distance or that the ferrodolomite zone is continuous, but the evidence suggests that this is the case.

These ferrodolomite zones have irregular transitional contacts with the greenstone, and the evidence points to a replacement of the greenstone along broken or shear zones. The origin of the carbonate minerals is uncertain. Some of the material may be derived from the alteration of the ferromagnesian minerals of the original lavas by hydrothermal processes. The source of the heat, and perhaps of some of the solutions, may have been the Baldie granite intrusive which outcrops about 2 miles to the east, but which may underlie the Fennell formation of Gold Hill at a relatively shallow depth.

No systematic sampling has been done to determine the values, but the presence of free gold scattered over such a length of deposit suggests that the zone might warrant careful investigation.

Wind Pass

This property is located on the plateau, 2 miles southwest of the crest of mount Baldie, at about 5,300 feet. It is now reached by a zigzag pack trail which leaves the main road near the south end of Dunn lake. The property is recorded in the names of Oscar Hargen, Olie Johnson, and Thos. Campbell.

The country rock of the vein is the upper micropegmatite facies of the micropegmatite-pyroxenite sill which trends in a north-south direction just east of the boundary of the Fennell formation. The deposit consists of a quartz vein with a general east-west strike and a northerly dip varying from 35 degrees to 80 degrees.

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The walls are definite and relatively smooth. The vein is offset in at least two places by crossfaults of small displacement. It varies in width from a few inches up to 36 inches, and averages probably 15 to 18 inches. It is characterized by pinches and swells both vertically and horizontally.

The west end of the vein consists of a highly fractured quartz filling, in which there are scattered minor amounts of chalcopyrite and pyrite. Grains of native bismuth occur here and there through the quartz, and almost any of the vein stuff pans fine gold. In some of the oxidized and broken material from the sides of the vein, leaves of native copper occur binding the fragments together.

The eastern half of the vein differs considerably in mineralogy and structure. It is much less quartzose and much less regular than the western part, and consists largely of discontinuous lenses of the solid bluish lodestone variety of magnetite, which is coated with limonite along all its fractures. Free gold may also be panned from this lodestone.

The intermediate part of the vein shows a gradation between these two types.

The vein has been followed by stripping, trenching, and open-cutting for about 200 feet. At its west end the vein enters a thin-bedded chert zone of the Fennell formation and becomes barren. At the east end it spreads into a number of lenticular lodestone masses. Deeper exploration may prove it to be continuous. At the bottom of the deepest pit on the vein—27 feet measured on a dip of 35 degrees—the vein is 36 inches wide.

The mineralization took place, probably, under deep-seated conditions, and was the result of contributions from the Baldie granite which outcrops 1½ miles to the east. As the contact of the Baldie batholith plunges westerly it may not be very deep below the Wind Pass outcrop.

No systematic sampling was done by the writer, but the owners report as follows:

(a) Assays of solid lodestone showed values in gold of $81 and $232 per ton.
(b) A 15-inch channel sample in one of the pits across solid lodestone assayed $67 per ton in gold.
(c) In 1916, 31½ tons of mineral were shipped to Trail, from which the following assay was reported: 2·48 ozs. of gold, 0·9 oz. of silver, and 1½ per cent of copper.
(d) In 1917, 29½ tons were shipped to Trail, from which the folowing return was obtained: 2.14 ozs. of gold, 1.5 ozs. of silver, and ½ per cent of copper.

Sweet Home

This vein occurs at an altitude of 5,000 feet and is located about 600 yards south of the Wind Pass. It is reached by a trail running south from the main Wind Pass trail. The property is controlled by the owners of the Wind Pass.

A quartz vein 8 to 15 inches wide crosses the contact of the micropegmatite pyroxenite sill and the banded chert of the Fennell formation. The strike varies from north 60 degrees west to due east, and the dip from 30 degrees to 40 degrees north. The vein, towards its eastern exposures, seems to become dissipated in the micropegmatite.

The vein is impregnated with pyrite, trivial amounts of chalcopyrite, small grains and minute specks of gold, and a few grains of native bismuth. It has been exposed by trenching and open-cutting for a distance of 400 feet, and the deepest pit is about 10 feet. No assay results are available to indicate the value of this lode. The vein is small, and the gold values would have to be high to make it worth mining.

The Sweet Home deposit is believed to have an origin similar to that of Wind Pass vein.

Allies

This prospect is on the west side of the river, half a mile west of the main road and 2 miles north of Chinook Cove. A wagon road from the highway leads almost to the property. The altitude is 2,000 feet above sea-level or 750 feet above river level. The two claims are recorded in the name of Maria d'Yongh Smith.

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The deposit occurs in rocks of the Badger Creek formation. A series of thin-bedded rusty weathering quartzites, striking north 50 degrees west and dipping 35 degrees southwest, is injected concordantly with a number of buff-coloured brownish-weathering sills, varying in thickness up to 10 feet. The larger sills carry rectangular-shaped phenocrysts of an undetermined feldspar in a dense buff groundmass. The narrower sills resemble felsite, and are markedly banded parallel to their contacts. These intrusives are impregnated with large numbers of cubo-pyritohedrons of pyrite. A series of at least three white quartz veins with crush zones filled with dolomite or ankerite cement, strike parallel with the stratification of the quartzites. They mostly occur immediately adjacent to the sills. The country rock close to its contact with the veins contains serpentine and dolomite, and has a decided greenish tinge.

Small amounts of pyrite, galena, and chalcopyrite are disseminated through the quartz veins. Systematic sampling of these veins was not done by the writer, but the owner reports attractive assay results.

Glacial drift and forest obscure the veins, which are exposed only in a few trenches, the deepest of which is 8 feet. At the bottom of this pit, a strike fault cuts off the quartz vein. The mineralization seems to be due to contributions from the sills. This inference, however, is based on areal relations only. The age and parent magma of the sills could not be determined on account of lack of exposures.

Homestake

This prospect is located on the north slope of the valley of Jamieson creek, 2 miles west of the river road. It does not occur on the North Thompson Valley geological sheet, but a special trip was made to examine it. It was under bond to J. T. Robinson and associates, of Kamloops. The outcrops are found at altitudes of 2,500 to 2,600 feet in a rolling park-like country sparsely clothed with jackpine. A serious handicap is the lack of water nearer than Jamieson creek.

Dawson examined this property in 1888, and briefly describes the local geology and the veins. He reports assays from 0·583 ounce of gold and 2·525 ounces of silver to 1·108 ounces of gold and 34·243 ounces of silver.[1]

On the property, brownish-weathering, highly fractured porphyritic quartz monzonite cuts biotite schist and argillite of the Cache Creek group. White quartz veins, and branching stringers occur along joint planes and prominent fractures in the intrusive rock. These are mineralized with scattered grains of pyrite, galena, arsenopyrite, and sphalerite. In certain cases there is a concentration of these minerals near the foot-wall. Five veins have been opened up by means of shallow pits and a shaft 75 feet deep. The veins strike north 15 degrees to 30 degrees west and dip from 90 degrees to 60 degrees west. They vary in thickness from 6 inches to 15 feet, but their longitudinal extent could not be determined. The shaft—on the largest vein—follows the hanging-wall down to 75 feet, at which depth the quartz appears to be barren. The writer suggested that a crosscut be driven 15 feet southwest into the foot-wall, and that this crosscut be carefully sampled. The veins seem to be genetically associated with the intrusive and to have been dependent upon it for the supply of their metalliferous contents.

GOLD: PLACER

Louis Creek

Small amounts of placer gold have been obtained from lower Louis creek.[2] No. exploration of the gravels has been carried out that warrants the statement that pay dirt might be encountered in appreciable quantity. During 1921, W. J. Smith, of

[1] Geol. Surv., Can., Sum. Rept., 1888, p. 337 B.
Geol. Surv., Can., Ann. Rept., vol. VII (N.S.), 1894, p. 337 B.
Geol. Surv., Can., Ann. Rept., vol. IV (N.S.), 1891, p. 60 R.
[2] Geol. Surv., Can., Rept. of Prog., 1877-78, p. 155 B.

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Louis creek, and five men, were engaged in diverting the creek to a new channel, so as to sluice the gravel of the present bed. Small amounts of gold were recovered from the gravel excavated from the diverting ditch. The gold was probably originally derived from the disintegration of quartz veinlets in some of the schists of the Shuswap region.

Threemile Creek

During the season, M. B. Roper and four or five men were exploring the gravels of Threemile creek, a tributary of Lemieux creek, a short distance north of Mount Olie. A shaft sunk 45 feet through the river gravel to reach bedrock, encountered a flow of water that seriously handicapped the work.

The upper 5 or 6 feet of the gravel is very coarse, and is reported to carry values up to $1 per cubic yard. It is underlain by lighter, better assorted gravel which carried much lower values. It seems probable that the lower, lighter gravel is a part of the valley fill of the larger Lemieux creek, and that the top heavy gravel is a deposit from the rapidly flowing Threemile tributary.

Above the shaft the stream emerges from a gorge cut through a heavy deposit of roughly stratified boulder conglomerate of the Chu Chua formation. The gold in the top gravels seems to be a concentration from the breaking down of this conglomerate. Small flakes and minute grains of gold can be readily obtained by panning the surface gravels in the locality of the shaft.

SILVER-LEAD-ZINC

Queen Bess Mine

The Queen Bess mine is located on the steep eastern slope of the North Thompson valley about 600 yards east and 720 feet above Auldgirth (Blackpool) station on the Canadian National railway and is outside the map-area. A chute connects the main workings with the mill which is built at the foot of the slope, and on a level with the railway track. The property is now under the management of O. A. Thomas, consulting engineer, of Seattle.

The country rock consists of the greenish pillow lavas of the Fennell formation. These are traversed by east-west buff-coloured shear zones, locally called dykes, highly charged with ankerite and dolomite. These zones are of irregular width, and show transitional contacts with the greenstone. The pillow structure of the lava is exceedingly well exemplified near the face of the crosscut tunnel, where the oval-shaped pillows are completely altered to buff ferrodolomite, whereas the matrix of the pillows is still green. Much of the ferrodolomite is decomposed to an iron-stained clay difficult to handle.

Two main veins, the Cameron and Bigelow, occur on levels Nos. 2 and 3. The Cameron strikes north 45 degrees to 50 degrees east and dips 50 degrees to 70 degrees northwest. The Bigelow, 130 feet to 200 feet southeast of the Cameron, strikes north 20 degrees to 30 degrees east and dips from 80 degrees northwest to vertical. The veins have in most cases definite walls. The fissures in which the vein material occurs maintain a fairly uniform trend in the unaltered greenstone, but where they enter the shear zone of ankeritic greenstone or ferrodolomite, they break up into a network of branching fractures. The veins vary in width from 1 inch to 5 feet, but average probably not over 12 to 15 inches. Where they traverse the greenstone, they are as a rule bordered by 2 to 6 inches of hard, buff-coloured rock of similar origin to the main zones of ferrodolomite.

Tabular to lenticular masses of nearly solid sphalerite and galena occur within the veins. The sphalerite is a beautiful coarse-grained resin variety mixed with a much smaller amount of fine- to medium-grained galena. Minor amounts of tetrahedrite occur. Lean parts of the veins contained disseminated particles of the sulphides in a quartz and quartz-dolomite gangue. In one stope a tabular mass of

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solid sulphides, up to 38 inches in thickness, was encountered. Minor amounts of these sulphides occur disseminated through the larger ferrodolomite masses near the positions of some of the vein fissures.

In the upper workings, several well-mineralized veins contain chiefly the oxidized minerals of zinc, lead, and copper. Cerargyrite is reported from these workings, but the writer did not recognize any in the field. No recent development has been carried on above level No. 2, so that little can be said regarding these oxidized zones.

The material mined as ore is said to average about 5 per cent of lead and 6 ounces of silver per ton. The first mill run of approximately 720 tons is reported to have given the following concentrates:

27 tons of lead concentrates assaying 40 to 50% Pb, 12% Zn, and 48 ozs. Ag per ton.
and
78 tons of zinc concentrates assaying 48% Zn, 7 to 8% Pb, and 14 ozs. Ag. per ton.

The Queen Bess is primarily a zinc blende deposit.

The only suggestion that can at present be offered regarding the origin of the veins is that they are genetically related to bodies of intrusive rock which cut the Fennell formation to the east. This occurrence is similar to that at the Gold Hill prospect.

The veins have been explored on three levels. The lower or No. 3 level, 720 feet above the railway, is 600 feet long, and enters the hill in an easterly direction. At 180 feet it cuts the Cameron vein which has been followed for about 80 feet on either side of the crosscut. From the southwest drift, a winze was sunk 100 feet on the vein, and at the 50-foot level in this winze an intermediate level was driven on the vein and the ore was stoped. The Bigelow vein, which the crosscut intersects at 300 feet, was drifted on for about 100 feet, beyond which the vein becomes a mere fissure or else anastomoses. Considerable stoping has been done on each of these veins.

No. 2 level is 300 feet above No. 3. The Bigelow vein on this level has been drifted on for over 100 feet, and a small amount of stoping has been done. The minerals are both sulphides and carbonates.

The mine has been closed since July, 1920.

Homestake Mine

The following notes have been contributed by C. O. Swanson, who made a special study of this property:

The Homestake mine is situated on the northern slope of the Sinmax Creek valley, about 3 miles west of Skaam bay, Adams lake (Figure 19). The main adit is in the rocky gully of a small stream emptying into Sinmax creek from the north, and is about 800 feet above the bottom of the creek. A wagon-road runs from Louis creek to Skaam bay and passes within a mile of the workings.

The deposit occurs in the Bastion schist (of Daly), which is part of the Barrière formation of this report. Near the mine the country rock is a quartz-sericite schist, impregnated with pyrite, which on oxidation gives the rock a decidedly yellow colour. The planes of schistosity, which are parallel to the original bedding, strike north 60 degrees west and dip 25 degrees to 40 degrees northeast. A high degree of fissility characterizes the schist, producing the appearance of a phyllite. The disintegration and creep of the schist, combined with the oxidation of the pyrite, account for the large talus slopes of yellowish platy fragments.

In the schist are intercalated two tabular bodies of fine-grained barite. The upper body is 12 feet thick at the outcrop, and the lower one 9 feet. They are separated by 150 feet of schist containing some barite. The lower deposit has been traced along the strike for 80 feet.

The barite is greyish-white and has a marked thinly-laminated structure parallel to the planes of cleavage of the schist. It does not cleave readily, however, along these bands. The analysis of an average specimen from the barite zone shows the

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presence of 85 per cent barite, 5 per cent silica and alumina, 8 per cent metallic minerals (galena, sphalerite, pyrite, tetrahedrite, and chalcopyrite), and 2 per cent undetermined material.

In close association with the barite zone and cutting it in places are many narrow quartz veins, which are usually barren, but which here and there contain barite, galena, and pyrite.

At first glance the barite appears to be syngenetic with the schist. But a detailed examination of the field relations and a study of many thin sections and polished surfaces shows that both the barite and the metallic minerals are a replacement of the schist. Some of the features leading to this conclusion are as follows:

The deposits occur in a more or less vertical zone characterized by the presence of barite, which does not appear elsewhere in the country rock to any extent.

Pyrite is clearly a replacement of the schist, and where pyrite and barite occur together, they appear to be of simultaneous origin.

The presence of galena and tetrahedrite, both high in silver, suggests that they were deposited by ascending solutions.

There is no evidence to show that the barite had a different origin from the metallic minerals. It occurs with them in quartz veins, and the fabric of the ore does not show the metallic minerals distinctly replacing the barite, as, for instance, the pyrite replaces the schist.

For these reasons amongst others, the origin of the deposits is held to be hypogene. The source of the solutions which contributed the barite and the metallic minerals is doubtful, as no intrusives outcrop near the mine. However, certain structural relations suggest the possibility of a body of younger granite underlying the district.

In 1893-94 twenty tons of ore averaging 80 ounces in silver were shipped from the property. Most of the development was done about 1917. A crosscut intersects the lower barite body 170 feet from the mouth, and from it drifts were run each way. The western opening met a fault beyond which the ore was lost. From the eastern drift a raise was driven in barite to the surface. A short drift running west from a point 40 feet up this raise encountered a fault, probably the same as the one mentioned above.

According to the statement made by R. W. Thompson, in the Annual Report of the Minister of Mines for British Columbia, for 1917, the general average of the ore in sight is: silver 9·75 ounces per ton, copper 0·22 per cent, and gold 0·02 ounce per ton. Assays of ore specimens and mineralogical determination of the constituent minerals show that the silver is mostly contained in the tetrahedrite.

MISCELLANEOUS MINING CLAIMS

Fortuna

The Fortuna property is located at Blucher Hall in the southwest corner of the map-area. The lower workings are a few feet above the level of the road. The nearest railway siding is at Louis Creek, 8 miles distant along a good wagon road. Mr. W. J. Smith, of Louis Creek, is part owner, and local representative of the company.

The country rocks belong to the Barrière formation and consist of argillaceous schist, with greyish streaks and fragments, and lenticular masses of quartz; massive white quartzite impregnated with pyrite; sericite schist; schistose quartzite; and a zone of greyish, medium-grained dolomite. These sediments strike about north 80 degrees west and dip 45 degrees to 55 degrees north.

A 12-foot bed of medium-grained grey dolomite lying between quartzite walls is impregnated with coarse-grained cubical pyrite. About one-half of the dolomite volume has been replaced by the pyrite. Traces of copper mineralization are

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present, and minor amounts of galena. Some quartz stringers also carry small quantities of galena. W. J. Smith reports the presence of pyrrhotite and arsenopyrite, but none was recognized by the writer.

W. J. Smith states that analyses of parts of the pyritized zone showed platinum up to 0·2 ounce a ton and $2 a ton in gold. Shipments of this material have been made from time to time to Pittsburgh, Pa.

The character and mineralogy of the deposit do not in the least suggest the presence of platinum. In order to determine this point, a few picked samples, taken under Mr. Smith's supervision, were submitted to the Mines Branch, Ottawa, for assay, but not one of them gave even a trace of platinum or silver, nor more than a trace of gold.

The trivial amount of gold and the entire absence of arsenic seem to confirm the absence of platinum.

Development consists of two crosscut tunnels, a lower one (255 feet long) at an altitude of 2,005 feet; and an upper one 500 feet long at an altitude of 2,115 feet. The upper one cuts the pyritic zone at 420 feet from the portal. Some open-cutting has been done along the outcrop at an altitude of 2,350 feet.

Skookum Claim

This is a small prospect with workings between altitudes of 3,300 and 3,365 feet, located half a mile north of the Fortuna. An open-cut with a 7-foot pit has been excavated at the higher location and a crosscut tunnel 143 feet long goes into the hill at the lower elevation, but does not reach the zone of mineralization.

The deposit consists of a 3-foot zone in the Barrière quartzites impregnated with pyrite and some chalcopyrite. The width of the mineralization varies from 20 to 36 inches at the outcrop, and there is reported to be 15 inches of solid pyrite in the bottom of the pit. The strike is north 80 degrees west and the dip 30 degrees north. Stripping and trenching at different points farther east suggest that this zone might have a considerable longitudinal extent.

The average value across a mineable width would probably be below commercial grade.

The property is recorded in the name of W. J. Smith of Louis Creek.

Mann Creek

A small prospect was being explored by Alfred Mann, of Auldgirth (Blackpool), on the south bank of Mann creek about 1½ miles from its mouth.

Some stripping and shallow open-cutting show a black graphitic schist associated with the Fennell greenstones and abundantly stained with blotches and traversed by filaments of azurite and malachite. A barren-looking quartz vein cuts through the formation at this locality. No sulphide minerals were seen, and insufficient work had been done to determine even the trend of the deposit. Its origin is quite obscure.

North Barrière Lake

Several small prospects are located near North Barrière lake. This district is several miles east of the sheet, but two days at the end of the season were spent in examining the prospects (Figure 19).

The only prospects worth mentioning are the Anaconda group, belonging to the Johnson brothers, Fosborg, Bilen, and H. D. Macdougall, located on Berk creek; the Lucky Boy group, belonging to Joe Conway and associates, on the northwest shore of the lake; and the Wah Wah claim of Bendeline and Hillyard, also on the northwest side of the lake.

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The Anaconda is a pyritic replacement in a dolomite zone in the quartzites of the Barrière formation, and consists of very low grade material. Minor amounts of galena and zinc blende occur with the pyrite. There is nothing to suggest any possibility of commercial value. Traces of copper and gold are the only indications.

The Lucky Boy group is the merest prospect. A tunnel was being driven into the hill through the Barrière argillaceous sericite and chlorite schists. Blotches and irregular masses of the copper carbonates stain the walls and back of the tunnel various shades of green and blue. An open-cut farther to the northeast revealed the same low-grade mineralization. The source of these oxidized copper minerals was not recognized, and no definite trend could be discovered for the mineralization.

The Wah Wah claim is located at an altitude of 3,360 feet on the northwestern slope of the lake trench. An open-cut and some stripping reveal a solid mass of pyrrhotite with small amounts of chalcopyrite and pyrite. The enclosing green schists are similarly mineralized, but to a much less extent. It is possible that the sulphides carry an appreciable amount of gold.

This district is favourably located geologically for prospecting, being within 2 miles of the contact of the Baldie granite batholith, but for mining its distance from a railway would be a handicap.

LIMESTONE

Some of the white limestone beds of the Barrière formation just east of mount Armour have been explored to ascertain their value as sources of lime. Some of these consist of relatively pure calcium carbonate. No assays were made.

GENERAL CONCLUSION REGARDING MINING PROSPECTS ALONG NORTH THOMPSON RIVER

The southern part of the North Thompson map-area seems unfavourable for the discovery of valuable metalliferous deposits. It is too far from the seat of igneous intrusion. The northern part of the area, especially beyond the limits of the map, seems more favourable, however, and the country within a couple of miles of the contact of the Baldie batholith should be carefully prospected. A thick covering of glacial drift and a dense forest mantle very greatly enhance the difficulties of the prospector.

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LARDEAU MAP-AREA, BRITISH COLUMBIA

By M. F. Bancroft

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Illustration

Figure 24. Index map of Lardeau area, Kootenay district, B.C. 108

The field work in Lardeau map-area (Figure 24) in 1921 consisted of further systematic mapping of the geology, and investigation of ore deposits. The writer's field work had covered, by the autumn of 1920, a wide strip of country between Slocan mining area and the 20-mile railway belt out from Camborne. The section of the railway belt on the northwest side of Lardeau area is exceedingly rugged and practically devoid of trails, and only part of the topography has been mapped.

Field work was commenced at Revelstoke in the latter part of June. Snow remained on the summits until late in the season and the autumn rains set in about the middle of August, permitting only a short working season. Efficient assistance in the field was rendered by two student assistants, H. T. James and G. F. Barnwell. Three local men were engaged to help in back packing and axe work. The writer wishes to acknowledge in particular the interest taken in the work by Arthur Johnson, Gold Commissioner, A. G. Langley, Resident Mining Engineer, and Walter Bews, Mayor of Revelstoke.

GENERAL GEOLOGY

The different rock formations underlying the Lardeau map-area southeast of Incomappleux river were summed up in the table of formations in the Summary Report, 1920.[1] The same formations or their equivalents are to be found in the 20-mile railway belt on the west side of Selkirk mountains. The field data obtained in 1921 relate to the distribution and structural features of these rocks.

Both stratified rocks and igneous rocks occupy wide areas in the Lardeau map-area. The stratified rocks form a thick cover into which granite and similar rocks have been intruded. Some of the igneous bodies reached high enough in the earth's crust to establish intrusive contacts with the uppermost strata found in the region. Deep erosion has laid bare these igneous bodies over wide areas in the Selkirk region northward from the International Boundary. The batholiths are exhumed to a stage at which they are seen in contact, in some places with the basement rocks, and at many other points with the upper formations of the region. Areas of metamorphic rocks occur in proximity to the igneous bodies; and progressive metamorphism is shown in the stratified rocks upward from the intrusive contacts.

STRATIGRAPHY OF THE SEDIMENTARY FORMATIONS

All the stratified formations have been compressed into wide folds. Folding and erosion of the sedimentary cover have exposed all the different stratigraphic

[1] Geol. Surv., Can., pt. A, p. 99.

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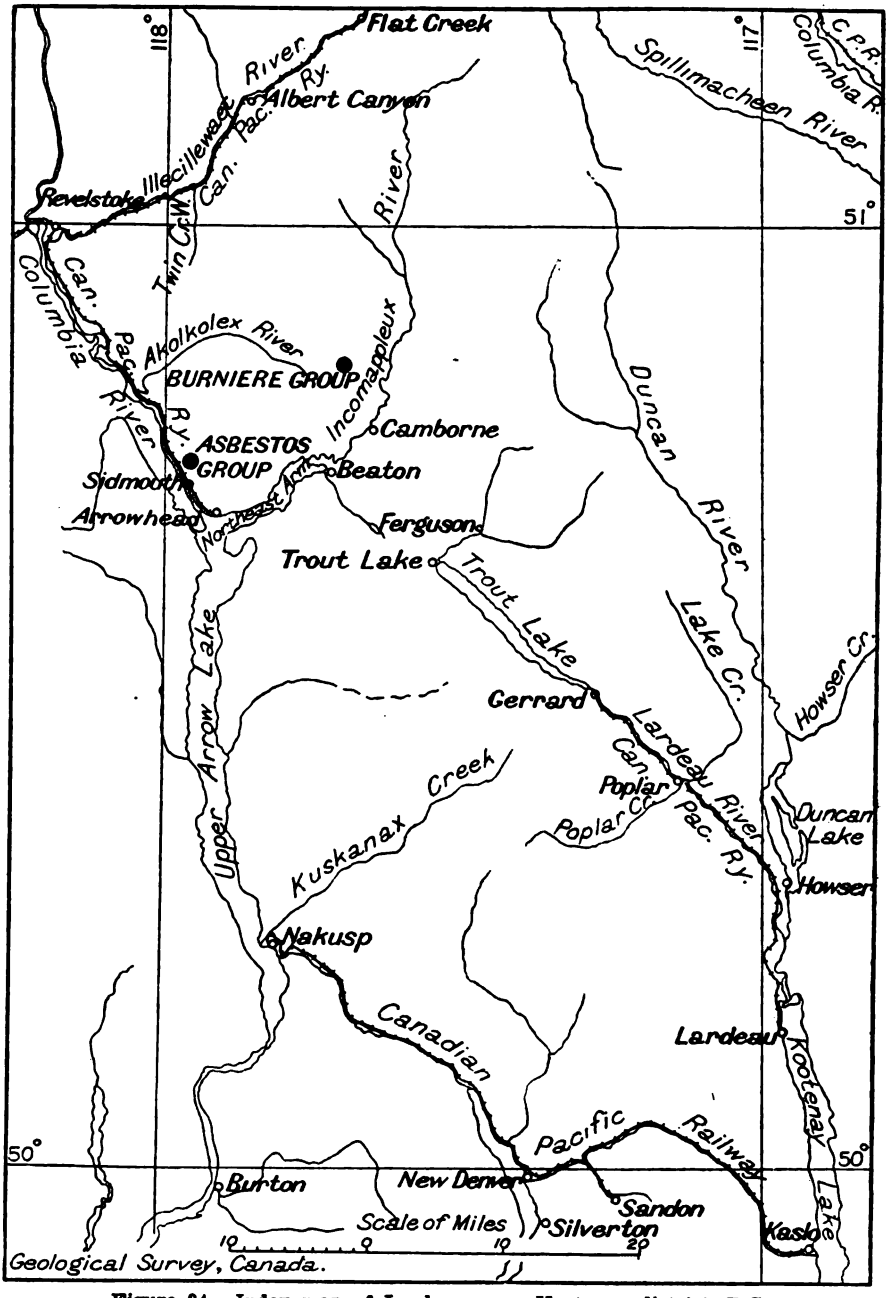

Figure 24. Index map of Lardeau area, Kootenay district, B.C.

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horizons; and crystalline basement rock types may appear in the same upland surface flanking much younger and less altered formations. The total thickness of sediments thus exposed aggregates several miles.

The stratified formations of Lardeau area fall into two distinct groups, a basal series consisting of quartzites, siliceous argillites and limestones and their metamorphosed equivalents, and a younger sedimentary series of carbonaceous marine beds, dominantly composed of argillites but including persistent limestone beds that are most numerous towards the base of the series. These correspond respectively to the Shuswap series and Niskonlith series into which Dr. G. M. Dawson in 1889, when examining mining areas in Kootenay district, divided the stratified rocks on the west side of the Selkirks. His mapping of the Shuswap series southeast of Revelstoke is consistent with the structure, in so far as older stratified beds appear in this section, in Illecillewaet and Columbia valleys. Dawson mapped a Shuswap-Niskonlith contact in the mountains on the west side of Kootenay lake which has proved to be continuous into Lardeau area. He inferred that a similar contact crossed the main line of the Canadian Pacific railway near Albert Canyon station, where metamorphosed rocks of the Shuswap series appeared to emerge from beneath the carbonaceous schists and argillites found in the railway section between Albert creek and Flat creek.

There can be no doubt that a considerable time interval is represented by the contact between the basement rocks and the Slocan (Niskonlith) series. There are possibly other gaps of lesser time value that have been overlooked, but the bulk of the sedimentary formations in Lardeau area must be regarded as either Carboniferous or pre-Carboniferous in age. Definitely Carboniferous marine fossils were obtained in 1917 from limestone and argillaceous beds of the Slocan (Niskonlith) series in the southern part of Lardeau area near mount Cooper.

STRUCTURE OF THE SEDIMENTARY FORMATIONS

The major structures in the stratified rocks are folds paralleling the Cordilleran trend. These folds are complex and show a great variety of minor flexures. The folds in the formations on the west side of the Selkirks in general trend northwest to southeast.

Open folding is characteristic of the basement formations which are composed of competent beds of quartzite and indurated siliceous argillites and limestones. The younger and softer beds infolded above the basement series are often tightly compressed in close folds. Some of the composite folds in the basement rocks attain several miles in width. West of Albert Canyon station well stratified metamorphosed beds appear at the track-level, rising abruptly 4,000 feet above the valley on the south side in the vicinity of the Albert peaks and continuing southwestward to form the height of land on the east side of Columbia valley. This structure represents a broad upwarp or arch in the basement formations, an unsymmetrical anticlinorium possibly more than 40 miles in width. This structure is continuous in the mountains on the west side of the Columbia beyond the limits of Lardeau map-area.

Warping of the major structures transverse to the trend of the region has given rise to minor folds favouring east to west axes. These folds affect the whole stratified series. Where the major folds plunge to the north or pitch to south, east to west folds represent the minor bucklings in the strata around the ends of these folds.

Faulting in Lardeau area is of minor importance to the folding. A break occurs in the formations near the headwaters of Twin Creek West. The creek appears to mark the fault line, for prominent limestone beds have been dropped down in the section on the east side of the creek and carried northward for a mile. The vertical displacement is only a matter of a few hundred feet. Faults in this mountainous region mostly show downthrow of the formations to the east and the displacement appears in this case to have occurred with a shift to the north of the fault block on the east side of this break.

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Igneous Rocks. The igneous rocks found in Lardeau area are all younger than the Carboniferous strata of the region. The first igneous invasion recorded includes gabbros and other basic rock types. Numerous sheet-like dykes of greenstone appear in the central part of the Lardeau syncline. These intrusives correspond to the Kaslo schists and form parallel bands following the trend of the folded formations. They are compact rocks that stood up in the weathering and erosion of the region to form the summits of ridges and peaks. They are most prominent in the region southeast from the headwaters of Akolkolex river. These basic igneous bodies preceded the invasion of the Nelson granodiorite. Many of them are greatly altered to chlorite schists, talcose schist, carbonate rocks, and in some localities to serpentine.

The granodiorite area in the vicinity of Revelstoke and extending up Illecillewaet valley appears to be in alignment with the wide belt of granite rocks that crosses the Lardeau area southeast of the Albert peaks. Northwestward beyond the Lardeau sheet a similar granodiorite belt extends through the Eagle Pass mountains and is shown on the Shuswap map-sheet (No. 604) extending as far as Adams lake.

The intrusive contacts of this batholithic area west of Revelstoke appear for the most part to be outlined in the basement rocks of the region. The contact extending along the south side of Illecillewaet valley between Revelstoke and Albert canyon pitches steeply to the south in the stratified formations, basement to and below the Slocan series. All the stratified formations above this intrusive contact are metamorphosed, and the contact pitches so steeply that few minor intrusives appear in the immediate vicinity to penetrate the overlying stratified rock cover. This intrusive contact and the stratigraphic contact crossing the height of land on the south side of Illecillewaet converge eastward so that the belt of basement rocks narrows and the igneous body is brought in close vertical relation to the upper formations in the Albert Peaks section.

ECONOMIC GEOLOGY

The mineral deposits in Lardeau area are closely associated with igneous intrusives. Wherever there are mineral indications there are at least minor igneous bodies outcropping in the same locality. The principal intrusive contacts bordering the granodiorite areas in Lardeau are similar to contacts southward in the Selkirk region and are probably well mineralized, but for the most part these contacts cross the mountains in the remoter parts of the area and have been little prospected. Few substantial efforts have been, or are being, made to prove the value of the mineral resources of this area. At the time the Slocan area was being prospected many claims were staked at widely scattered points, and some along well-defined mineral zones in this part of the Selkirk region, yet only very limited mining developments materialized. The majority of the mineral claims are in the Slocan formation, extending diagonally across the area between the head of Kootenay lake and Revelstoke. Some properties were located in the early days east of Albert canyon near Illecillewaet and on Incomappleux river, south of Flat creek. No important mineral discoveries have yet been made in the mountains along the south watershed of Illecillewaet river, though there are places where the rocks are impregnated with rusty-weathering sulphides, containing pyrite, pyrrhotite, and some chalcopyrite. A few mineral occurrences have been reported from the Akolkolex drainage basin just south and east of this watershed, within the bounds of Revelstoke mining division. The geological formations found in this section are the extension northwestward of the rocks crossing Lardeau, Trout Lake, Ainsworth, and Slocan mining divisions.

The metalliferous ores mined in the Selkirk region carry values in gold, silver, lead, zinc, and copper.

GOLD

The gold quartz veins found in the central mineral belt from Cascade creek on Lardeau river through to Camborne on Incomappleux river merit investigation. The gold quartz at Poplar resembles the gold quartz in the mineral belt crossing Incomap-

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pleux river. Associated with the quartz are green patches of material made up of several hydromicas varying from colourless to bright green, the green being due to the presence of a small amount of chromic oxide. These hydromicas have the optical and other physical properties of the mineral mariposite. The veins are associated with a carbonate rock which appears to be in general an intimate mixture of quartz, carbonate minerals, and hydromicas of the mariposite group. Some quartz showing the green hydromicas was found by the writer this season in the talus slopes about the head of Greely creek, but none of the carbonate rock was seen in that locality.

NICKEL

Specimens of the gold quartz and carbonate rock from the Berniere property were found by R. A. A. Johnston to contain minute specks of metallic sulphides that gave traces of nickel; some of the specks may be millerite (nickel sulphide), but others are probably nothing more than nickeliferous pyrite. The carbonate constituents in the rock associated with the gold quartz from the Berniere are somewhat complex. The principal base metals noted are iron, calcium, magnesium, and nickel; traces of manganese and cobalt show in some of the trials; but qualitative experiments indicate rather wide variations in the proportions of the bases mentioned even in different portions of the same sample. The status of the nickel content of the carbonates is a matter of uncertainty, but its behaviour towards reagents points very strongly to the presence of zaratite, a hydrous carbonate of nickel often found in emerald green crusts.

MANGANESE

Carbonates that show on weathering a considerable content of manganese occur in grey quartzites bordering a body of serpentine rock on the west slope of Sproat mountain. The serpentine carries a certain amount of carbonate material, and manganese carbonates occur as local replacements or fissure fillings in the sedimentary formations on the east side of the serpentine belt. The ground in this locality was staked several years ago for asbestos, which occurs in the altered serpentine rock.

Several small open-cuts have been made showing the character of the manganese ore. Samples taken from the surface this season by the writer were reported on by Eugene Poitevin as follows: "The material consists for the most part of granular, compact, greyish to pinkish carbonates of manganese, iron, calcium, and magnesium. These carbonates probably form isomorphous series. Some of them are near rhodochrosite in composition, others nearer to mangancalcite or mangansiderite. The specific gravity varies from 3·30 to 3·40, and the optical properties indicate that the material is not of uniform composition. About 20 per cent of the material is unattacked by hydrochloric and nitric acids. The microscopic residue appears to be quartz. A few quartz crystals coated with manganese oxides appear encrusted on one of the specimens.

The hydrous manganese oxides coating the carbonates are admixed with certain quantities of limonite. It is evident that the manganese oxides were derived from the transformation of the carbonates."

ASBESTOS

Asbestos Group. The property mentioned above is known as the Asbestos group of claims and sit situated to the east of the Columbia river, about 1½ miles in direct line from the Canadian Pacific Railway track at Sidmouth, a flag station 3 miles north of Arrowhead. The claims are at an elevation of 4,200 feet above sea-level, approximately 2,800 feet above the railway.

Assessment work in the early part of the summer disclosed some high-grade asbestos of the fibrous chrysotile variety in open-cuts made in the serpentine. The owners are R. Armstrong of Sidmouth and J. T. Lauthers of Revelstoke.

Chrysotile veinlets may be found in almost any serpentine area. The surface showings where chrysotile is mined in Quebec are seldom conspicuous. The Asbestos

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group of claims is located on a belt of serpentine rock that represents a very much altered basic igneous intrusion. This igneous body has the form of a wide dyke or elongated stock that cuts across a series of quartzites, crystalline limestones, and argillaceous schists. The original igneous massive has been altered to serpentine and talcose schists.

In the ground covered by the Asbestos group the serpentine forms an escarpment or series of rocky bluffs starting at an elevation about 2,600 feet above the railway on the northwest slope of mount Sproat. The outcrops of the serpentine occur over a vertical distance of 350 feet on a 25-degree slope, so that the belt has a width of about 1,000 feet and is continuous for some distance along the strike.

Good samples of both cross fibre and slip fibre may be obtained from the open-cuts on the Asbestos group. Mr. A. G. Langley examined the property, and samples submitted by him to R. A. A. Johnston proved to be chrysotile or serpentine asbestos. The specimens of cross fibre collected by Mr. Langley showed a fibre length of ½ inch to ¾ inch. Mr. Johnston states that these specimens are quite as good as, if not superior to, much of the South African stock now being used in increasing amounts as a filler.

The writer visited the property in August and obtained a variety of specimens of different grades. The best cross fibre in these specimens is straw-yellow and would yield a product of fair length, strength, and silkiness that would find a ready market.

A specimen showing the best quality of slip fibre consisted of fine, silky fibres 4 to 5 inches in length. This was pronounced by Mr. Harvie, who has been working in the Quebec asbestos area, to be very desirable material, corresponding to certain varieties of material from South Africa.

Some of the specimens of cross fibre were found to be somewhat harsh and brittle and would lack the tensile strength for a good spinning fibre; it should, however, make a good filler for textiles. The very short-fibred material could be used to advantage in compositions such as wallboard, tile, and roofing.

The serpentine on the Asbestos group of claims is a very much altered type of rock. A considerable part of it is altered to compact talc schists. Other minor alteration products are calcite and magnesite; possibly some of the green patches in the rock may be actinolite. Associated with the cross-fibre asbestos is the brittle, fibrous, green mineral picrolite.

Talc. Some of the talc in this serpentine might prove of commercial value, since the property is close to transportation. Varying amounts of either talc or serpentine asbestos are found in the small open-cuts that have been made on the property. The talc, where it occurs in quantity, is light grey, but soft, yielding a white powder. Some of the samples show material that would make a medium-grade talcum powder or might be useful as a paper filler and in compositions.

The Mount Sproat section appears to warrant further exploratory work to determine whether chrysotile, talc, or manganese occur in workable deposits. The Asbestos group has yielded the best samples of chrysotile so far found in British Columbia.

Iceland Spar. R. W. Brock, reporting on Lardeau area in 1903, pointed out that a small piece of calcite, so clear and unchecked as to belong to the Iceland spar variety, had been found near Whiskey point on the northeast arm of Upper Arrow lake. It was also pointed out that if this material could be found in quantity it would be a most valuable discovery, as this form of calcite is in demand for optical purposes and the known deposits are almost exhausted.

A discovery of Iceland spar was reported this season near the headwaters of Lake creek, a tributary of Lardeau river. This locality is on the northeast side of Lardeau area, where the limestone formations that occur near the base of the Slocan series strike northwest and southeast across the country. The writer was unable to examine the deposits, but samples obtained from outcrops give promise that the right sort of material has been found in place.

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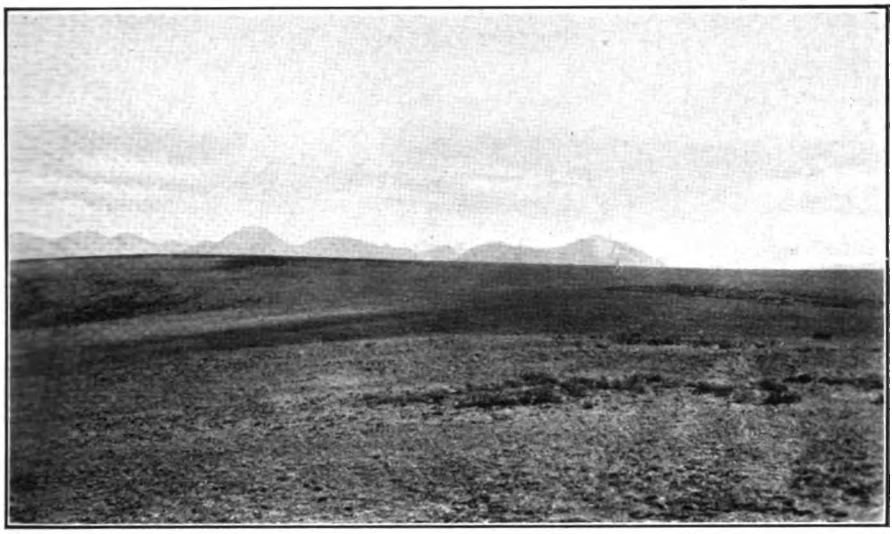

A. View of the upland surface, showing the flat-topped character of the plateau. (Page 3.)

B. Workings of the Mount Cameron property. The outcrop of the vein may be seen in the slide of broken material in the middle of the picture. (Page 6.)

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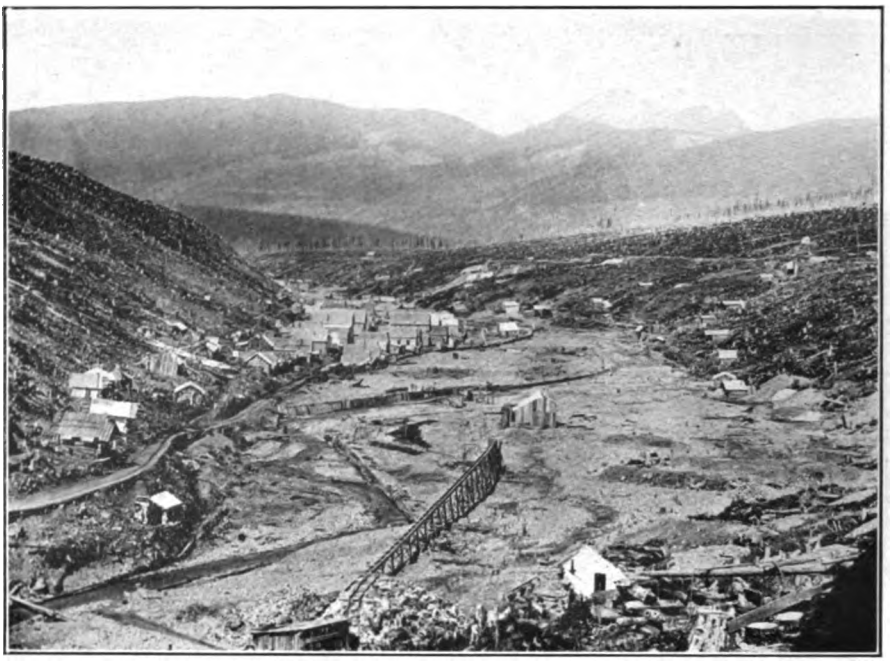
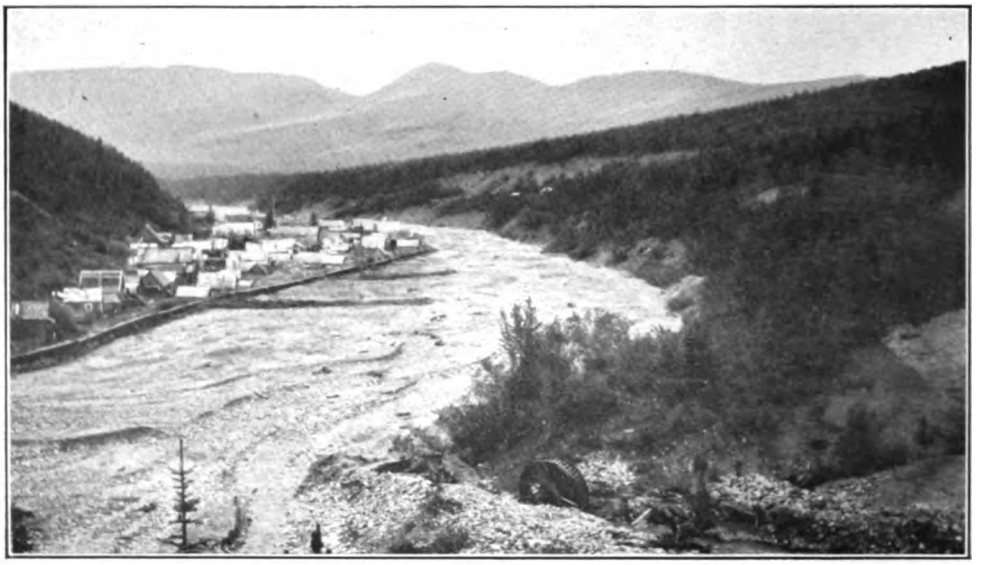


View down Williams creek from Black Jack cut, Bakerville area, B.C. (Photo, 1868, by R. Maynard, Victoria, B.C. (Page 61.)



B. View down Williams creek from Black Jack cut, Barkerville area, B.C. (Photo, 1921.) (Page 6.)

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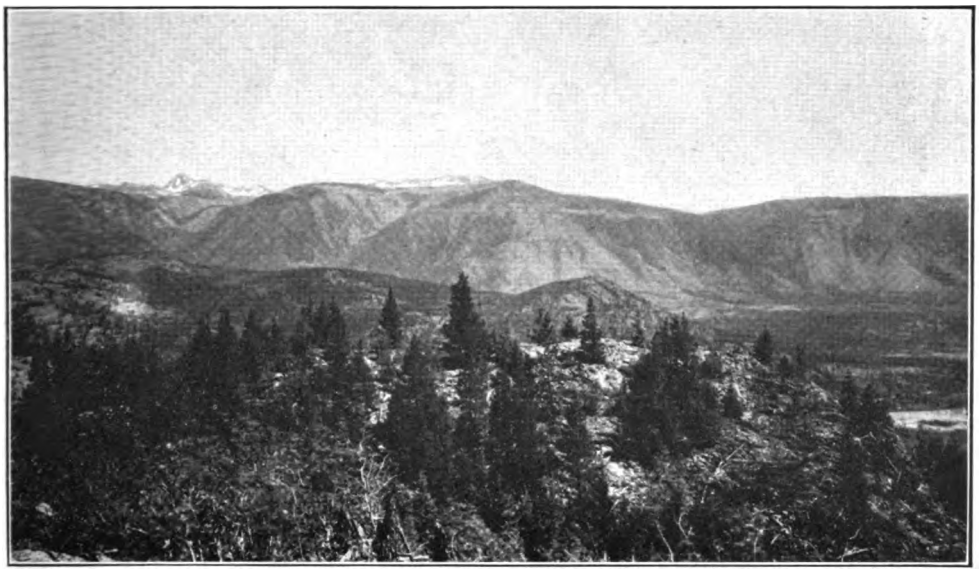
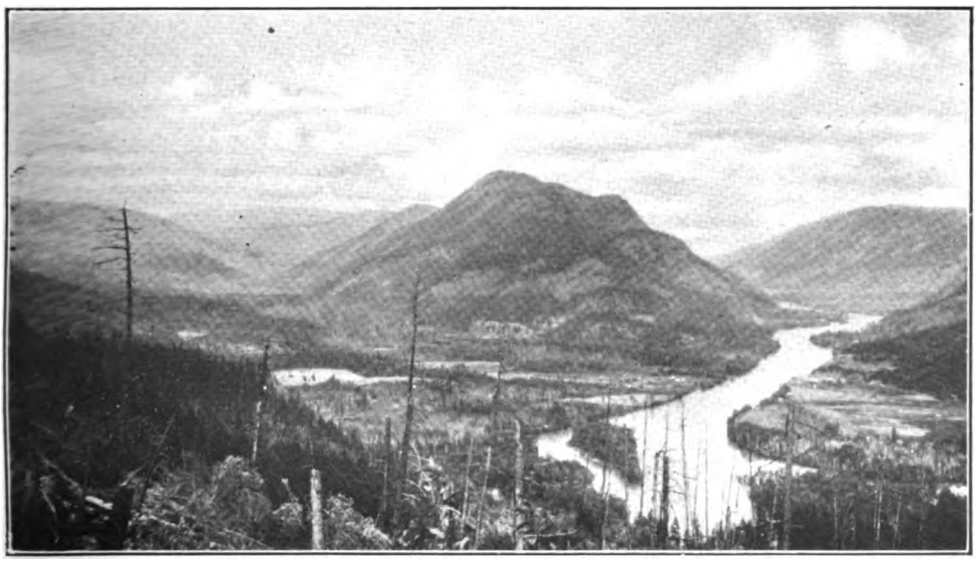


A. View eastward across North Thompson valley from point 2 miles south of Mount Olie village. Picture shows the youthful topography of the North Thompson trench, the old-dissected peneplain above, the topographic unconformity between these two, and Dunn peaks in the far distance, which are monadnocks standing above the uplifted peneplain. (Pages 74, 89.)



B. View up North Thompson valley showing Mount Olie village and "roche moutonnée" character of Fennell pillow lava on Mount Olie ridge. (Page 74.)

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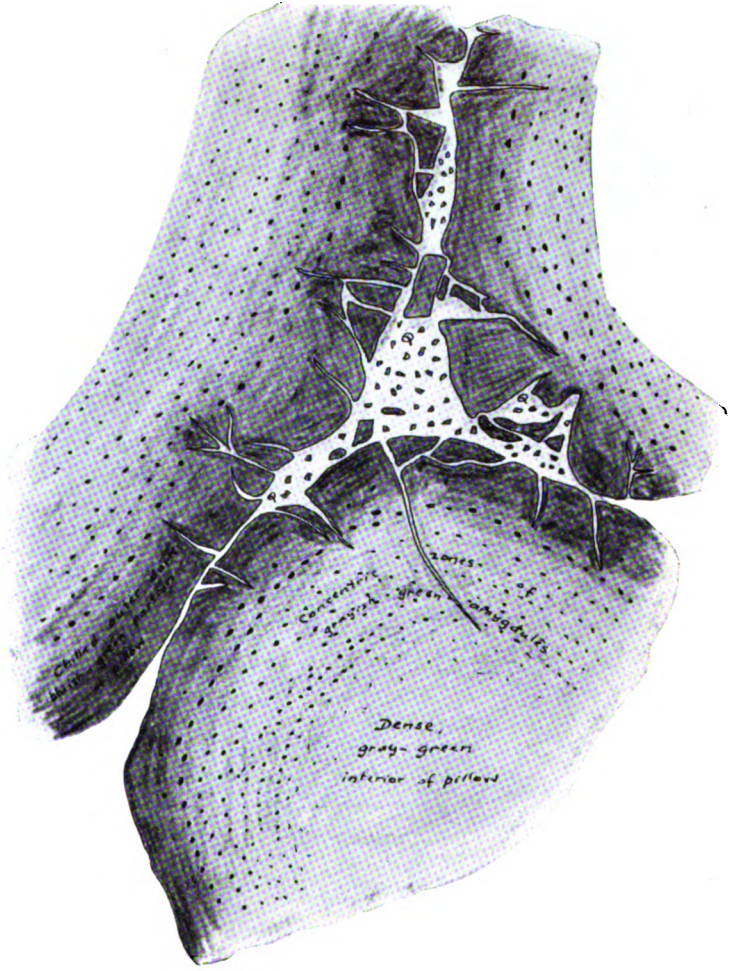
A. Fennell greenstone showing pillow structure, in Canadian Northern railway-cut north of Chu Chua, (Page 77.)



B. Sketch of parts of three contiguous pillows, to illustrate the brecciation of their peripheries, the fillings of chalcedonic quartz (Q), and the zonal arrangement of the amygdules. Natural size, approximately 11 inches. (Page 77.)

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[1] NOTE: All localities not otherwise designated are in British Columbia.

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CANADA
DEPARTMENT OF MINES
HON. CHARLES STEWART, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

GEOLOGICAL SURVEY
W. H. COLLINS, DIRECTOR

Summary Report, 1921, Part B

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SUMMARY REPORT, 1921, PART B

HAY AND BUFFALO RIVERS, GREAT SLAVE LAKE, AND ADJACENT COUNTRY[1]

By A. E. Cameron

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Illustration

Map 1585. Mackenzie River basin, northwestern Canada .. 2

INTRODUCTION

The presence of asphaltum and oil-bearing rocks in the Mackenzie basin and on the shores of Great Slave lake has been known ever since the earliest explorers visited that part of the Northwest Territories, but the remoteness of the region has retarded the study and exploitation of these resources. The continually increasing demand for petroleum products, however, and particularly the excitement caused by the reported strike of large oil fields near Calgary, aroused considerable interest in the possibility of discovering new fields on Peace and Athabaska rivers and farther north. In 1914-15 many claims were staked for petroleum and natural gas in the vicinity of Nintsi (Windy) point on the north shore of Great Slave lake where tar pools have been known from early times. The writer was instructed to examine the district about the western arm of Great Slave lake and, in particular, to endeavour to determine whether the rocks show any of the conditions favourable for the accumulation of oil.

The summer field seasons of 1916 and 1917 were spent in examining the district. A study of the shorelines of Great Slave lake occupied the major part of the season of 1916; in 1917 an exploration was made of some of the principal rivers flowing into the lake from the south. The more important geographical results of these explorations were the traverses of Hay river from where it is crossed by the 6th meridian of the Dominion Land Surveys, to its outlet on Great Slave lake; of Buffalo river and its source, Buffalo lake; of the lower parts of Kakisa river and of the north shore of Great Slave lake from the outlet at Mackenzie river to the north arm of the lake. Mackenzie river from where it leaves Great Slave lake to the mouth of Kakisa river with its numerous islands was also surveyed and some very necessary corrections were made in

[1] In order to include conveniently in one volume as much new information as possible regarding the occurrence of petroleum in the Mackenzie River region, at this time when so much interest in being taken in exploration for petroleum, this report by Mr. Cameron is included in the Summary Report for 1921, although the field work was done some years previously. Following it are reports by E. J. Whittaker, M. Y. Williams, and G. S. Hume upon more northerly sections of the region and one by D. B. Dowling dealing with more general aspects of the problem of finding petroleum in the Mackenzie region.
Director.

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previous maps of this part of the river. These surveys were made with a micrometer telescope and compass, and were checked by sextant observations for latitude.

LOCATION AND EXTENT OF AREA

The area examined lies between latitudes 58° 20′ north and 62 degrees north and longitudes 111 degrees and 119 degrees west. This immense area, comprising approximately 61,400 square miles, is one of the largest blocks of practically unexplored areas of the Dominion. It embraces a large part of the valley of Hay river, the whole of the drainage system of Buffalo river, and the large basin of the west arm of Great Slave lake. It lies partly in the province of Alberta and partly in the Northwest Territories.

Field work was of necessity limited to traversing the more important waterways. Information regarding the interior of the country was gathered from the few reports that have been written and from personal communication with the inhabitants. South of the 60th parallel of latitude the Topographical Surveys Branch, Department of the Interior, has several base and meridian lines and the reports of the surveyors contain good accounts of the topography of the country. North of the 60th parallel, the country, except narrow strips in the vicinity of travelled routes, still remains largely a land unknown.

ACKNOWLEDGMENTS

G. L. Kidd conducted the instrumental work of the surveys in a most capable manner. The thanks of the writer are due to many residents of the district for assistance and general kindnesses, especially to the Reverend A. J. Vale and the Reverend G. W. Bowring of the Anglican Mission school at Hay river, to the Reverend Father Bousso of the Roman Catholic mission at Hay river, to the staffs of the various Hudson's Bay Company's posts, and to officials of the Forestry Branch, Department of the Interior.

Acknowledgment is also due to Charles Camsell and E. M. Kindle, of the Geological Survey, for many helpful suggestions and kindly criticism in the preparation of this report. Mr. Camsell directed and supervised the field work, and in 1916 made an extensive journey over the area, visiting the field party in August of that year. Mr. Kindle and E. J. Whittaker made a collection of fossils from the area in 1917. The results of study of these and of the collections made by the writer in 1916, together with Mr. Kindle's suggestions regarding the correlation of strata, have made it possible to compile the geology of the area, shown on the accompanying 50-mile map (No. 1585).

PREVIOUS WORK[1]

Almost all the earlier explorers of the country made some reference to the physical geography and geology of parts of Great Slave lake. Samuel Hearne crossed the eastern arm of the lake in 1772, Alexander Mackenzie traversed the west arm in 1789, and Franklin, Richardson, Back, and others spent some time in the vicinity of the lake. These explorers, however, were more interested in the country to the north and their reports carry little information regarding the country near the lake.

In 1886, R. G. McConnell[2] made a geological examination of the south shore from Slave river to Mackenzie river, and ascended Hay river as far as Alexandra falls. He traversed the north shore of the lake from Mackenzie river

[1] The name Little Buffalo river has been changed by the Geographic Board to Livock river, but has been retained in this report, as the accompanying map had been published before the change was made.

[2] McConnell, R. G., "Report on Exploration in the Yukon and Mackenzie Basins," Geol. Surv., Can., Ann. Rept., new ser., pt. D, vol. IV, 1888-89.

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TERTIARY

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as far east as Nintsi point. The published report of these explorations contains the most detailed information relative to the geology and physical geography of the region.

Wm. Ogilvie[1] in 1887 surveyed the south shore of the lake from Mackenzie river to Slave river.

During the seasons of 1899 to 1902 Robert Bell and J. M. Bell[2] surveyed and made a geological examination of the east arm of the lake and the east shore of the north arm, but the north shore of the west arm though traversed by Mackenzie in 1789, and probably by Franklin and Richardson in 1825, had never been surveyed previous to 1916.

Slave river has been the main waterway for travel to the north country since the earliest times. At the time of Mackenzie's explorations fur traders had already established a trading post on Great Slave lake. Peace river was ascended by Mackenzie[3] in 1792 on his journey across the continent from Montreal to the Pacific ocean. Petitot[4] claims to have discovered Kakisa (Beaver) river in 1875 and about the same time Alexandra falls on Hay river were named by Bishop Bompas. Whether the bishop ascended Hay river from Great Slave lake or descended it from Vermilion is not known. In the early nineties a small party of prospectors bound for the Yukon descended Hay river to the lake, building a small cabin and wintering on the portage at Alexandra falls. In 1902 C. Camsell[5] ascended Little Buffalo river from a point near Fort Smith to the divide between that river and Jackfish river, and descended Jackfish river to Peace river. Sergeant Mellor, of the Royal Northwest Mounted Police, made a patrol up Buffalo river and across Buffalo lake in 1909.[6] Prospectors have also been up the river, according to Indian reports, and the ruins of their cabins are still to be seen along the river. Sergeant McLeod[7] of the Royal Northwest Mounted Police, who made a winter patrol in 1911 from Vermilion across the Caribou Mountain plateau and down Buffalo river to Great Slave lake, was the first white man to traverse this region. In 1911, Hulbert Footner,[8] a journalist, descended Hay river from Vermilion portage to Alexandra falls. In 1914, J. R. Akins[9] ran the 29th base-line of the Dominion Land Surveys across the lower end of Caribou Mountain plateau, and in 1916 projected the 6th meridian[10] north to the northern boundary of Alberta at the 60th parallel of latitude.

GENERAL CHARACTER OF THE DISTRICT

Caribou mountains, which lie south of the 60th parallel of latitude, form the principal watershed between the waters tributary to Peace river and those tributary to Hay and Buffalo rivers. They are in reality the escarpment bordering a large, gently rolling plateau elevated about 3,000 feet above sea-level, and

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[1] Ogilvie, Wm., "Exploration Surveys of Parts of Lewes, Tat au Duc, Porcupine, Bell, Trout, Peel, and Mackenzie Rivers," 1887-88, Dept. of Interior, report of 1890.

[2] "Mackenzie Basin," Geol. Surv., Can., Ann. Rept., new ser., pt. A, vol. XII, 1899; also Ann. Rept., new ser., pt. E, vol. XII, 1899.

[3] Mackenzie, Alexander, "Voyages from Montreal on the River St. Lawrence Through the Continent of North America to the Frozen and Pacific Oceans in the Years 1789 and 1793."

[4] Petitot, Emile, Autour du Grand Lac des Esclaves.

[5] Camsell, C., "Region Southwest of Fort Smith," Geol. Surv., Can., Ann. Rept., new ser., pt. A, vol. XV, 1902-03, p. 143.

[6] Mellor, Sergt., "Patrol Along the South Shore of Great Slave Lake in Connection with the Location of the Wood Buffalo," Report of Royal Northwest Mounted Police, 1910.

[7] McLeod, Sergt., "Vermilion to Hay River on Great Slave Lake," Report of Royal Northwest Mounted Police, 1911.

[8] Footner, Hulbert, "New Rivers of the North," 1914.

[9] Akins, J. R., "29th Base Line between 5th and 6th Meridian," Report of Dept. of the Interior, Topographical Surveys Branch, 1914.

[10] Akins, J. R., "6th Meridian between 27th Base and Northern Boundary of Alberta," Rept. of Dept. of Interior, Topographical Surveys Branch, 1916.

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from 2,100 to 2,500 feet above the surrounding country. This plateau extends southward to within 15 miles of Peace river and the northern escarpment is clearly visible from Buffalo lake from which it is not more than 30 miles distant. Camsell[1] reports the eastern limit to be about 8 or 10 miles west of Jackfish river. The western limit is not visible from the valley of Hay river, but probably extends to within 30 miles of that stream. These boundaries give the plateau an area of approximately 9,600 square miles. Very little is known concerning this area. The 29th base-line of the Dominion Land Surveys crosses the southern edge of the plateau and Akins[2] reports the slopes as heavily wooded with spruce and jackpine and the top as lightly wooded with stunted spruce and covered with moss. Sergeant McLeod[3] states that a number of lakes lie on the top of the plateau, one of which is about the size of Lesser Slave lake. He traversed the plateau from south to north and reports it to have a typical rolling topography characterized by low hills of glacial drift and muskeg or swampy lowlands. Small moss-fringed lakes abound and are drained by numerous swift-flowing creeks. The banks and valleys of the streams are composed of clays and gravels and their beds are full of boulders of igneous rocks washed out of the glacial boulder clay.

Southwest of the Caribou Mountain plateau and connected with it by the height of land between Peace and Hay rivers is another small plateau, 2,500 feet in elevation, called Watt mountains. The intervening height of land between Peace and Hay rivers is about 1,500 feet in elevation and is formed largely of glacial drift.

Peace river from Fort Vermilion downstream approximately marks the southern boundary of the area under discussion. Just above Fort Vermilion the river lies in a deep valley, but within a short distance the banks fall away, and from Vermilion to near the confluence of Jackfish river it flows through a broad, gently rolling plain which on the north rises gradually to Caribou mountains. Towards the height of land between Watt and Caribou mountains this plain is characterized by large, open prairie sections separated by areas carrying a light growth of poplar and willow. Numerous prairie sections, also, are said to diversify the plain area to the east lying between Caribou mountains and Peace river. These areas are well watered by numerous streams tributary to Peace river, the most important being Paddle or Boyer river, and Caribou, Lawrence, Deer, and Jackfish rivers.

Very little is known of the district lying to the east of Caribou mountains and north of Peace river. In the vicinity of Little Buffalo and Jackfish rivers, Camsell[4] reports the country to be a gently rolling upland breaking abruptly at the 200-foot escarpment of the salt plains near Fort Smith. Numerous muskeg and swampy areas occur between low hills of glacial drift covered with jackpine and poplar.

With the exception of the traverse of Buffalo river and Buffalo lake made by the writer in 1917 and described in detail in later pages of this report, the whole of the vast territory lying between Great Slave lake and Caribou mountains and between Hay and Slave rivers is virtually unexplored. Sergeant McLeod[5] reports the country seen when looking northward from the summit of

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[1] Camsell, C., "Region Southwest of Fort Smith," Geol. Surv., Can., Ann. Rept., 1902-03, p. 149.

[2] Akins, J. R., "29th Base-Line between 5th and 6th Meridians," Ann. Rept., Dept. of Interior, Topographical Surveys Branch, 1914-15, p. 67.

[3] McLeod, Sergt., R. W., "Vermilion to Hay River, Jan., 09," Royal Northwest Mounted Police report, 1909, p. 178.

[4] Camsell, C., "Country Southwest of Fort Smith," Geol. Surv., Can., Ann. Rept., new ser., vol. XV, 1902-03.

[5] McLeod, Sergt. R. W., "Vermilion to Hay River, Jan., 09," Royal Northwest Mounted Police Report, 1909, p. 178.

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the Caribou escarpment to be a gently rolling, well-wooded plain dotted with numerous small lakes. Near the salt springs near Fort Smith, there are many open prairie sections interspersed with areas supporting a light growth of spruce and poplar; and much open prairie country is said to occur in the region between Little Buffalo and Buffalo rivers. Slave river in this part of the area flows through a broad alluvial plain of its own making, the western boundary of which is approximately Little Buffalo river. South of Pine point on Great Slave lake, the land rises with relative rapidity until, in a distance of 3 miles, it has an elevation of about 200 feet above the lake-level. A narrow strip of swampy muskeg country lying at about water-level along the lake shore appears to have been formed in lagoons cut off from the lake by barrier beaches of gravel and sand and subsequently partly filled and reclaimed by vegetation. The absence of any large tributaries east of Buffalo river indicates that the height of land between this river and Little Buffalo river lies very close to the former stream and that, consequently, the large area between these two streams and south to Caribou mountains drains chiefly to the east into Little Buffalo river.

The country west of Hay river is little known. Akins[1] reports that the country for 35 miles north of Hay river, adjacent to the 6th meridian, is gently rolling and well watered by numerous streams flowing east to Hay river. Then there is an abrupt rise at the escarpment of Cutknife hills to an elevation of 2,700 feet. Cutknife hills appear to be a broad, gently rolling plateau dotted with numerous small lakes which apparently drain westward to the headwaters of Kakisa river. Near Grumbler rapids on Hay river the escarpment of Swede mountains, 2,500 feet in elevation, shows to the west at a distance of about 15 miles. The escarpment is apparently a continuation of that of Cutknife hills to the southwest and, probably, connects with the Eagle Mountain escarpment to be seen to the south from Great Slave lake and Mackenzie river. From Eagle Mountain escarpment northward to the lake shore, and between Hay and Kakisa rivers, extends a low, flat, swampy country scarcely higher than Great Slave lake. It is reported by the Indians to be dotted with small, shallow lakes separated by stretches of muskeg. An old Indian canoe route connects Hay and Kakisa rivers through these lakes and swampy areas.

The country to the north of Great Slave lake and west of the North arm, Preble[2] reports to be "a low, broad plateau dotted with many lakes and muskegs. It contains no rivers of importance and is mainly rather thinly wooded, though a number of large prairies occur in the western part north of the outlet of the lake." Seen from the shore of the lake it appears to be a gently rolling plain with ridges of glacial drift separating low-lying muskeg areas which stand only slightly higher than the lake.

The region north of Great Slave lake is underlain by the Precambrian formations and is rocky and rolling, having been heavily eroded by the Keewatin continental glacier. Vegetation is scant, and confined to the low ground between the rocky ridges, where stunted spruce and poplar grow in a mossy muskeg soil.

HAY RIVER

Hay river, rising in the foothills of the Rocky mountains to the north of Fort St. John, B.C., and fed by numerous small streams, is one of the largest tributaries of Great Slave lake. It crosses the 6th meridian a few hundred yards south of section corner 25-114-1. From this point, though of a meander-

[1] Akins, J. R., "6th Meridian—27th Base-line to 60th Parallel," Ann. Rept., Dept. of Interior, Topographical Surveys Branch, 1916.

[2] Preble, E. A., "North American Fauna," No. 27, U.S. Dept. of Agriculture, Bureau of Biological Survey, 1908.

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ing character, it holds remarkably well its direction of magnetic north (north 35° 30′ east astronomical) throughout the distance of 225 miles to Great Slave lake.

Throughout the 26 miles from the 6th meridian to the mouth of Meander river at Hay River outpost, the river has an average width of 200 feet, and is very swift and broken by a succession of rapids. The valley is less than half a mile wide and the adjacent country is gently rolling, drift-covered, and wooded with scrubby spruce and poplar, much of which has been burnt over in recent times.

North of Hay River outpost the valley widens and shallows and the river, straightening its course, widens to 400 to 600 feet and flows smoothly and sluggishly for 116 miles through a flat muskeg and brûlé country, which is in places relieved by low hills of glacial drift.

Devonian limestones come to the surface 116 miles below the mouth of Meander river and form low ramparts in the river valley that cause the river to narrow and the current to increase. For the next 33 miles, rapids occur in quick succession wherever the channel has been cut down to the limestones, until finally, 149 miles below Hay River outpost, the river plunges 106 feet, forming Alexandra fall. From the fall the river flows rapidly for a mile through a narrow gorge and then makes a second leap of 46 feet, forming Louise fall. The portage trail leaves the river on the left bank above Alexandra fall, leads for 2½ miles through a flat marshy plain forested with white spruce and jack-pine, and returns to the river where the limestone cliffs have been broken down to a slope.

The falls are due to a band of soft shale 47 feet thick interstratified with massive bedded limestones which overlie a thick series of soft clay shales. McConnell[1] shows that the rate of recession of the falls has been almost identical with that of Niagara falls. He says: "Niagara falls are generally regarded to have receded 6 miles since they were brought into existence by the elevation of the country at the end of the Glacial period and on Hay river the distance between the point at which the limestone band makes its first appearance and the lower falls is almost exactly 5 miles and between the same point and the upper falls 6 miles."

Below Louise fall the river has cut a narrow gorge about 250 feet deep in the limestone, through which it rushes for a distance of 6 miles before it clears the escarpment. For the succeeding 40 miles it flows with steadily diminishing velocity until about 4 miles from the lake it loses itself in a maze of channels amongst the delta deposits. Only one of these channels, however, finds its way to the lake separately, the others all coming together and issuing as one stream into the lake.

BUFFALO LAKE

Buffalo lake covers approximately 200 square miles. It is very shallow, its depth scarcely exceeding 10 feet in any place. Confined on the north by a low range of hills of glacial drift, the lake acts as a collecting basin for the waters draining the northern slopes of Caribou mountain. Three comparatively large streams flow into the southern end of the lake. Each of these is building a delta which is gradually encroaching on and slowly filling in this part of the lake. The whole shoreline is low and swampy, particularly on the south side, where in places willow and alder bushes are growing in 2 feet of water. A few islands, composed of glacial boulders of Precambrian granites and metamorphics, occur along the northern shore. The smaller of these resemble cairns and are bare of

[1] McConnell, R. G., "Explorations in the Yukon and Mackenzie River Basins," Geol. Surv., Can., Ann. Rept., new ser., pt. D, vol. IV, 1889.

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vegetation, but upon the larger ones, scrubby spruce, poplar, and willow have found a foothold. These islands represent outliers of the low, east and west glacial morainal ridge that forms the north shore of the lake. The lake is evidently the remnant of a much larger morainal lake of early postglacial times.

BUFFALO RIVER

Buffalo river, which discharges from the northeast corner of Buffalo lake into Great Slave lake, flows northwest 5 miles, cutting through the low range of hills that bound the lake on the north. It then makes a wide swing to the right and after following a general course of magnetic north (north 36 degrees east astronomical) for 25 miles, swings in another wide curve, known as the Big Bend, after which it resumes a true north course for 25 miles to Great Slave lake. From Buffalo lake to the Big Bend the river valley is cut through a series of morainal ridges separated by flat muskegs and brûlé. The outside of each curve has a bank cut into glacial clays and gravels. Boulder rapids separated by stretches of smooth, though swift-running, water, are numerous. Below the Big Bend the ridges become more numerous and of greater height and the cut banks frequently show sections of glacial clays and drift 80 to 100 feet high. Here the current increases and the river runs turbulently in a succession of rapids amongst and over the large boulders washed from the drift. At a few places along its course it has cut into the underlying Devonian limestones, forming low ramparts similar to those on Hay river. About 3 miles above its mouth it suddenly expands and, diverging into numerous channels, loses itself in a braided channel amongst limestone gravel bars. These divergent streams reunite in a single stream which forces its way through a low barrier of glacial drift to Great Slave lake.

The volume of water carried by the river is subject to rapid fluctuation due to the shallow nature of Buffalo lake in which it has its source. Even comparatively light winds cause waves that quickly raise the level of the lake on the windward side. During strong winds a rise of 2 feet or more in the level of the lake was noticed and when the wind blows in the direction of the outlet the discharge down the river is greatly increased.

LITTLE BUFFALO RIVER

Little Buffalo river rises in Caribou mountains and follows an easterly course towards Slave river. It then swings north and closely parallels Slave river to Great Slave lake. It crosses the 60th parallel of latitude 28 miles west of Fort Smith and a portage 7 miles long connects it with Salt river near Fort Smith.

Little Buffalo river from the end of this portage to near its headwaters at the base of the Caribou plateau was examined by C. Camsell[1] in 1902. He reports a series of three falls occurring about 6 miles above the portage, giving a total drop of 71 feet. The falls are probably caused by an outcrop of limestone overlying gypsum beds similar to the Salt River escarpment. Camsell mentions no fossils from these limestones, but they probably represent a Middle Devonian horizon.

A traverse of Little Buffalo river from Salt River portage to Great Slave lake was made in 1920. The river averages 60 to 70 feet in width throughout the distance, has an exceedingly meandering course, but presents no hindrance to canoe navigation.

[1] Camsell, C., "Region Southwest of Fort Smith," Geol. Surv., Can., Ann. Rept., new ser., vol. XV, 1902-03, pt. A.

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For the upper 35 miles it borders an east-facing escarpment varying from 40 to 150 feet in height. This escarpment is a continuation of the Salt River escarpment and in all exposures Devonian dolomite limestones overlie the gypsum series. Gypsum creek, a small stream fed by springs in a sink-hole on the edge of the escarpment, enters from the left about 25 miles below Salt River portage, and slightly above this creek a portage 7 miles long connects the river with Slave river at Le Grand Detour. Below Gypsum creek the escarpment is not so high and swings west, and no rock outcrops are met with until the mouth of Log-jam creek is reached, 40 miles above the mouth of Little Buffalo river. At the mouth of Log-jam creek a bed of flat-lying limestones causes a small rapid, the only one between Salt River portage and Great Slave lake. The limestones, which are just below water-level, carry a fauna closely allied to that found in the limestones about Resolution. Log-jam creek was ascended about 16 miles. It flows through a flat muskeg country that has no pronounced relief; and it exposes no bedrock except just at its mouth. Below the creek the valley walls of Little Buffalo river are low and the adjacent country is a flat muskeg. An escarpment about 200 feet high shows to the west for the last 15 miles, but no rock outcrops in the valley.

MACKENZIE RIVER

Mackenzie river, where it leaves Great Slave lake, is divided by Big island into two channels. The southern one has a width of 7 miles at the lake, but in 5 miles narrows to 4 miles and becomes choked with islands. It carries the main flow of water and is used by the steamers, yet is shallow and navigation in low water is difficult. The current here has a velocity of at least 3 miles an hour. The north channel has a width of about a mile and a half where it leaves the lake, in only a few places exceeds 2 feet in depth, and shows very little current until close to its junction with the main channel at the lower end of Big island. Below Big island, Mackenzie river keeps an average width of about 4 miles for a distance of 20 miles and shows only a very slight current. This part of the river is known locally as Beaver (Kakisa) lake and is reported to be rarely more than 12 feet deep.

KAKISA RIVER

Kakisa river, which enters the Mackenzie from the south about 25 miles below Great Slave lake, was ascended for 8 miles, to Lady Evelyn falls. It is swift and shallow and almost unnavigable. The adjacent country is a low muskeg with occasional ridges of glacial drift which, where crossed by the river, form typical boulder rapids. About 6 miles above its mouth, Devonian limestones make their first appearance in the valley, forming low cascades where the river cuts across the beds. The valley here is from 60 to 80 feet deep and shows heavy deposits of glacial material overlying the limestones. Two miles farther upstream is Lady Evelyn fall where the river drops 48 feet over a limestone cliff. This fall is caused in the same way as Alexandra fall on Hay river. The limestones exposed are the same as those that form Louise fall; but the overlying shales seen on Hay river have thinned out; consequently Alexandra fall on Hay river is here represented by a long series of low cascades from 3 to 15 feet high. No gorge is developed below the fall, though the valley walls are steep and show occasional cliffs of limestones.

GREAT SLAVE LAKE

R. G. McConnell,[1] in 1887, accorded to Great Slave lake a superficial area, including islands, of approximately 10,400 square miles and ranks it fifth

[1] McConnell, R. G., "An Exploration in the Yukon and Mackenzie Basins, N.W.T.," Geol. Surv., Can., Ann. Rept., pt. D, new ser., vol. III, 1888-89.

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among the great lakes of the continent, being exceeded by Superior—31,500, Huron—23,800, Michigan—22,300, and Great Bear—11,400 square miles. Calculations based on the Dominion of Canada Railway map, issued 1914, slightly increase the areas of Great Bear and Great Slave, giving them 11,900 and 10,700 square miles respectively. Great Slave is divided into three arms as follows: West arm—5,430 square miles, East arm—4,120 square miles, and North arm—1,150 square miles. The writer's survey of the north shore of the West arm supplies more accurate data for calculating the area of this part of the lake; it indicates an area of 7,830 square miles, thus increasing previous estimates by 2,400 square miles. This increase gives Great Slave lake a total area of 13,100 square miles, or an excess of 1,700 square miles over Great Bear lake, and places it fourth among the great lakes of the continent.

Great Slave lake is about 300 miles long and in one place is over 60 miles wide. It had originally the form of a great cross with one arm penetrating the Precambrian crystalline schists and two others stretching north and south along the edge of the protaxis; the fourth extended over the flat-lying Palæozoic sediments to the west. The southern arm has been completely silted up and obliterated by Slave river.

The East arm, stretching about 200 miles to the east of Slave river, has an irregular outline and is dotted with many rocky islands. The water is said to be very deep and clear and to abound in fish of various kinds. The country north and east of this arm is described by Back[1] as one of bare, round-backed hills and ridges that rise gradually from the water's edge to a height of 1,000 to 1,200 feet.

The North arm, situated opposite the mouth of Slave river, has a width at its mouth of nearly 40 miles. Its eastern shore is a rugged, rocky country with many low, rocky islands offshore; whereas the western shore is flat, with sandy beaches and occasional wave-cut cliffs. The eastern shore was surveyed and examined in 1899 by J. M. Bell[2]; the western shore has been surveyed and geologically mapped by G. S. Hume, of the Geological Survey, since the time of the writer's visit to the lake.[3]

Exploration and examination of the western part of the lake—here referred to for convenience as the West arm—formed the major part of the writer's field work in 1916. Although a very large expanse of open water, and free from islands beyond 10 miles from shore, it is everywhere shallow, and sand-bars and reefs are reported to occur many miles out. It is slowly being filled by material brought down by Slave river, and the water, especially along the southern shore, is seldom entirely free from suspended matter. Towards the north shore the water is clearer, but even there a distinct cloudiness is noticeable and it is not until the northeastern shore is reached in the vicinity of the mouth of the north arm, that the water becomes clear. Sediment-laden waters are again observable in the vicinity of île les Bassée and île du Large, though they are more than 30 miles from the mouth of Slave river. The prevailing northeast winds cause an accumulation along the south shore of immense quantities of driftwood which sometimes takes fire and is often the starting point of destructive forest conflagrations. Piles of this wood 100 and more feet wide and several feet high are frequently to be found extending for miles along the shore.

The lake abounds in fish of many kinds, which should furnish a profitable industry when the country to the south becomes more settled and freight rates are reduced. Whitefish, jackfish, and trout are abundant, individual trout fre-

[1] Back, Captain George, "Narrative of an Arctic Land Expedition to the Mouth of Great Fish River and Along the Shores of the Arctic Ocean in the Years 1833-34-35."

[2] Explorations in Mackenzie District: Geol. Surv., Can., Ann. Rept., new ser., vol. XII, 1899, p. 103 A; vol. XIII, 1890, p. 53 A; vol. XII, pt. C.

[3] Geol. Surv., Can., Sum. Rept., 1920, pt. B.

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quently exceeding 50 pounds in weight. There is also taken from the lake the inconnu, or "conie," the edible qualities of which all but equal that of the northern whitefish. The inconnu is exclusively a northern species and is never found south of Fort Smith.

Description of the Shores of Great Slave Lake

The south shore from Stoney island west to Little Buffalo river is formed of delta deposits from Slave river that mark approximately the mouth of the pre-existing south arm. These fluvial deposits of crossbedded sands and silts are intimately associated with lacustrine deposits of a somewhat earlier period which extend as far south as Fort Smith. In places they are well covered with an abundant growth of excellent spruce. At Resolution a low range of hills rises above the silts and extends west into the lake, forming Mission and Moose islands and, still farther west, Burnt islands.

From the mouth of Little Buffalo river, which marks the western limit of the delta deposits, the shoreline is characterized by wide, shallow bays separated by low, gravelly or rocky points. Usually each bay has a gravelly or sandy beach behind which lies a narrow stretch of low, swampy muskeg or shallow, open lagoon. South of Pine point the ground rises gently inland until at a distance of some 10 miles it reaches an elevation of 300 feet above the present lake-level. This slope is well wooded with spruce, jackpine, and poplar and carries numerous well-developed old lake beaches which, extending in long, gentle curves, tend to follow the outline of the present lake shore. West of the mouth of Buffalo river the shoreline is generally low-lying and swampy with few pronounced points.

West of a line drawn from Hay river to Slave point on the north shore, the shores of the lake are formed presumably of soft shales, and the adjacent land is low-lying and swampy. Long stretches of spruce and tamarack muskegs reach inland from the lake. These are bounded on the south by Eagle mountains but the northern limit is not visible from the lake. Along this part of the shore, Precambrian erratics are abundant and frequently occur far enough offshore to endanger navigation. This part of the lake is very shallow and the shoreline in most places is formed of boulder pavements embedded in a soft blue-to-grey clay. Short, narrow points formed of boulders derived from the Precambrian rocks east of the lake are very numerous, particularly in the deep bay north of the outlet, and boulder reefs occur at long distances from the shore. All the points have a tendency to parallel the direction of glacial movement.

From Slave point the shore runs north for about 40 miles, then east for 25 miles, and then swings in a wide circle to the north arm. The entire shoreline shows clearly the effects of excessive glacial action. Many deep, narrow bays stretch inland approximately parallel to one another in a direction about south 60 degrees west magnetic, or north 85 degrees west (astronomical). That this direction is parallel to the glacial movement is shown by well-marked striæ on Nintsi point.

The heads of the bays are in most cases low and swampy, like those on the south shore, and show a well-developed boulder pavement of material derived from the Precambrian rocks to the east. Wide marshes, in many cases containing large open sloughs, stretch inland from the bays. On the broader points low, wave-cut cliffs in the limestone occur, though frequently the cliffs are situated some distance inland from the present lake shore. The narrow points show boulder pavements embedded in limestone gravels derived from the underlying sediments. A certain percentage of the boulders are probably glacial

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erratics, but undoubtedly the large majority have been derived from the glacial drift near the lake shore and from the lake bottom, and have been ice-rafted to their present position.

Distinct barrier beaches of limestone shingle are developed wherever the bedrock outcrops at water-level. Many of these extending in long, gentle curves enclose shallow, partly filled lagoons.

The inland country north of the lake is a low spruce and tamarack muskeg slightly higher than the lake, with numerous long, narrow hills rising 100 to 150 feet above lake-level. The hills, in many cases, show low, wave-cut cliffs, facing lakewards, at elevations above the present lake-level. Above and below these cliffs are numerous old lake beaches formed of limestone gravels washed out of the cliffs and clearly indicating changes in the level of the lake during early post-Glacial times.

One of the pronounced features of this region is the absence of drainage towards the lake. Throughout the entire 136 miles of shoreline between Mackenzie river and the North arm, only one small stream was found entering the lake.

The North arm marks the contact of the Precambrian rocks on the east with the Palæozoic sediments on the west; consequently the northeast shore, which is formed of Precambrian rocks, has a character entirely different from the others. It is rocky throughout and for the most part sparsely wooded except in the hollows. Boldly-carved and rounded hills of igneous and metamorphic rocks break off abruptly at the lake, and offshore are numerous irregularly-shaped, rocky islands. The shore is indented with many narrow bays and inlets which are mostly deep and afford excellent harbourage for small craft.

GENERAL GEOLOGY

DISTRIBUTION OF FORMATIONS

Except where the Precambrian rocks reach the surface, almost the whole of the vast district under consideration is mantled with a heavy covering of glacial drift, lacustrine, and fluvial deposits. Consequently, the underlying sediments outcrop infrequently, mostly in the river valleys where the erosive power of the rivers has cut through the superficial beds, or on the shores of the lake where ice and wave action have played a similar part.

The section of the region under consideration, which lies north of the 60th parallel of latitude, is underlain by flat-lying Palæozoic sediments of Silurian, Middle Devonian, and Upper Devonian age. No distinctly Lower Devonian sediments were observed and probably are not represented in the area. The stratigraphy as a whole resembles that of Manitoba, except that the Ordovician and much of the Silurian are absent. There also Tyrrell[1] was unable to locate outcrops carrying a definite Lower Devonian fauna.

At Little rapids on Peace river, soft shales carrying Upper Devonian fossils were found by Kindle unconformably overlying the massive gypsum beds. Exposures of the Gypsum series elsewhere in the district, however, as on Slave river and at the salt springs near Fort Smith, show these beds to be overlain by limestones carrying Middle Devonian fossils and this seems to be the correct sequence of the strata.

South of the 60th parallel the area between Caribou mountains and Slave river, and the Peace River valley as far west as Vermilion chutes, are also

[1] Tyrrell, J. B., "Report on North West Manitoba," Geol. Surv., Can., Ann. Rept., new ser., vol. V, 1890.

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underlain by Devonian and Silurian sediments. At the chutes, Upper Devonian limestones equivalent to the limestones on Hay river and the Chemung limestones of New York, are exposed. At Little rapids on Peace river and at several points on Slave river in the vicinity of Fort Smith, limestones carrying gypsum beds are exposed, which, on fossil evidence, are equivalent to the Gypsum and Upper dolomitic limestones of Upper Silurian age found east of lakes Manitoba and Winnipegosis, in Manitoba.

In the valley of Hay river above Grumbler rapids and on Peace river above Vermilion chutes, soft Cretaceous shales are exposed. On Peace river these have been called by McConnell[1] the Loon River shales and are, probably, equivalent to the Clearwater shales and tar sands of the Athabaska River section. The Cretaceous shales on Hay river are lithologically similar to the Loon River shales, but lack of definite palæontological evidence makes it seem advisable to give them a separate nomenclature and simply suggest the correlation.

The plateau areas shown on the map (No. 1585), so far as is known, show no rock in situ, but their topographical forms indicate them to be outliers of the Cretaceous sediments found on Peace river to the west and south. They probably contain representatives of the Peace River sandstones, Fort St. John shales, and Dunvegan sandstones of McConnell's Peace River section. They appear to be plateaus of circumdenudation carved out of horizontal beds of the Cretaceous, like Birch mountains and Buffalo Head hills to the south of Peace river.

Three unconformities break the continuity of sedimentation during the Palæozoic period in this region. It, therefore, follows that any given geological boundary may involve widely different formations in different parts of the region. The greatest of these unconformities is that at the top of the Precambrian. The hiatus here includes the late Precambrian, the Cambrian, Ordovician, and part of the Silurian. The incursion of the Silurian sea into this region engulfed an old land surface of well-developed hills and valleys. Some of these hills were at least 100 feet high and it is most probable that many of them had not been entirely buried under sediments when the Silurian sea withdrew. In Middle Devonian time the sea re-invaded a region of old Silurian sediments which were doubtless broken here and there by low knobs of Precambrian rocks. The warping and surface inequalities developed during the lower Devonian erosion interval left a highly uneven surface, parts of which were submerged and covered by Middle Devonian sediments, and other parts remained uncovered until Upper Devonian time. The third great unconformity of the section cuts out all the intervening formations between the Upper Devonian and the Cretaceous. A further unconformity, representing the long Tertiary time interval immediately preceding the Glacial period, marks the contact of the Quaternary and Cretaceous beds.

The several formations are indicated in the following table, together with a probable correlation with a composite Peace River, Manitoba, and New York section. From this table it is evident that lithological evidence alone is not sufficient to deduce the stratigraphical succession in the map-area. The order in which the strata were laid down and the suggested correlations with the composite section are based upon collections of fossils made by the writer from type localities and identified by E. M. Kindle.

[1] McConnell, R. G., "District of Athabaska," Geol. Surv., Can., Ann. Rept., new ser., pt. D, vol. V, 1890-91.

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Table of Formations

Period	Formation	Description	Thickness	Correlation
			Feet	
Quaternary.....	River and lake deposits	Sands, silts, and gravel beaches	.....	Agassiz silts, gravels, and deposits of present rivers
	Glacial deposits....	Till and boulder clays.....	.....	Glacial till
		Contact unconformable		
Cretaceous.....	Meander shales.....	Soft, greenish shales with sandstone beds and concretions	.....	Loon River shales
		Contact not exposed, probably unconformable		
Upper Devonian	Hay River limestones	Hard dolomitic limestones, shaly limestones, limy shales	300	Chemung
	Hay River shales...	Shaly limestones, soft clay shales with limestone, sandstone and ironstone bands	400	
	Simpson shales.....	Greenish grey clay shales, weathering to fissile shale	250	Portage
Middle Devonian	Slave Point limestones	Grey shaly limestones...	200	Manitoba limestones
	Presqu'ile dolomites	Hard crystalline dolomites, dolomitic limestones, thin beds grey shaly limestone	375	Winnipegosan dolomites
	Pine Point limestones	Soft, grey, shaly limestones, blue to black thin-bedded hard limestones, grey to brown shaly limestones	595	Elm Point limestones
		Contact unconformable		
Silurian	Fitzgerald dolomites	Grey dolomitic limestones with gypsum and anhydrite	275	Gypsum and Upper limestone of Manitoba
	Red beds.....	Red calcareous shale, red gypsum, salt, and red arenaceous shale	595	
		Contact unconformable		
Precambrian.....	.....	Hard red sandstones, granite		

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The following is a summary of Kindle's report on these collections:

Silurian. The Silurian fauna is represented by a single specimen of limestone showing a coral closely allied to if not identical with the well-known Guelph species *Pycnostylus guelphensis.* This specimen was collected from a point on the north shore of the lake about 5 miles west of Gypsum point. The same fossil has been found by Kindle in dolomitic limestones overlying gypsum beds on Peace river and at outcrops of Palæozoic sediments on Slave river above Fort Fitzgerald. The beds which furnish this coral fauna have been named the Fitzgerald dolomites.

Middle Devonian. The faunules from the south shore of Great Slave lake may be grouped in three lots.

The first group was collected from exposures in the vicinity of Pine point and furnished the following species:

Favosites sp. nr *limitaris*
Cyathophyllum richardsoni
Zaphrentis mcfarlani
Sponge spicules (*Hyalostelia*)
Stylolina fissurella
Chonetes pusilla?
Liorhynchus sp.
Productella sp.
Stropheodonta sp.
Atrypa reticularis
Martinia sublineata
Proetus sp.

This fauna suggests a palæontological correlation with the Elm Point formation of the Manitoba section. The beds containing this fauna have been called the Pine Point limestones. They represent the oldest Devonian formation in the region.

The second group was collected from exposures on Presqu'ile point and furnished the following species:

Actinostroma cf. *nodulatum* Nicholson
Favosites cf. *limitaris*
Atrypa spinosa
Martinia sp.
Stringocephalus burtini

The presence in the faunule of *S. burtini,* first found at Presqu'ile point by Mr. Kindle, indicates the equivalence of this horizon to the limestone at the Ramparts on lower Mackenzie river and to the Winnipegosan dolomites of the Manitoba section. The beds containing this fauna have been called the Presqu'ile dolomites. They immediately overlie the Pine Point limestones.

Kindle[1] has recently discussed the significance of *S. burtini* and the associated fauna in Devonian correlation. It has been shown to occur throughout most of the length of the Mackenzie basin. This important guide fossil of the Middle Devonian is widely known in Europe, but curiously enough has never been found south of Canada. The *S. burtini* fauna of the Mackenzie Middle Devonian is thus closely related faunally to the Middle Devonian of Europe and the British Isles and rather sharply contrasted with the faunas of the same general horizon in the United States.

The Upper Devonian fauna of this section is on the other hand most closely related to the Upper Devonian of the United States as the list of fossils in a later paragraph shows.

The third group, collected from Sulphur point, contains only a few fossils and these are poorly preserved. Species identified included:

Cyathophyllum richardsoni
Martinia sp.
Reticularia sp.

On the north shore of the lake similar limestones are exposed about Slave point and are to be found overlying Presqu'ile dolomites in the hills north of Sulphur bay. From this last locality the following fossils were collected:

Atrypa reticularis
Atrypa spinosa
Rhynchonella cuboides
Cyrtina hamiltonensis
Schizophoria striatula
Murchisonia sp.

[1] "The Distribution of *Stringocephalus burtini* in Canada," Trans. Roy. Soc. Can., vol. 15, 3d ser., 1921, pp. 21-24.

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This is the most representative collection from these beds and the presence of *C. hamiltonensis* indicates that these beds are probably equivalent to the Manitoba formation of the Manitoba section. The beds containing this fauna have been named the Slave Point formation.

Upper Devonian. Upper Devonian sediments are exposed in the valley of Hay river and on Peace river at Vermilion chutes. Fossils collected represent the same general fauna which is listed below:

Phillipsastrea hennahi	*Schizophoria striatula*
Heliophyllum parvulum	*Cyrtina hamiltonensis*
Cladopora sp.	*Cranæna cf. iowensis*
Stromatopora sp.	*Spirifer whitneyi*
Hederella canadensis	*Spirifer cf. subattenuatus*
Spirorbis omphaloides	*Atrypa reticularis*
Productella sp.	*Atrypa spinosa*
Stropheodonta sp.	*Paracyclas sp.*
Camarotoechia sp.	*Bellerophon sp.*

This fauna correlates with the upper part of the Iowa Devonian and with the Chemung of New York.

Thickness of the Section. With the exception of the section exposed on Hay river no exposures of the sediments show a complete section through even one formation. Hay river gives a fairly complete and measurable section through the Upper Devonian, at least to the bottom of the Hay River shales, and shows a total thickness of about 700 feet. No exposures of Simpson shales occur in the map-area but they are assumed to underlie the Hay River shales. An estimate based on Kindle's report of the sections exposed at Simpson[1] would indicate 250 feet as a maximum thickness for these beds. The Slave Point limestones are exposed only locally and their thickness can at present only be assumed. About 200 feet of recrystallized dolomites of the Presqu'ile formation are exposed above water-level at Nintsi point. The remainder of this formation and the thickness of the underlying formations down to the Precambrian are shown in the log of the Imperial Oil Company's oil well drilled at Nintsi point during the summers of 1920 and 1921, given on page 16.

[1] Kindle, E. M., Geol. Surv., Can., Sum. Rept., 1920, pt. B.

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Well Log

—	—	—	Thickness	Depth
			Feet	Feet
Middle Devonian	Presqu'ile dolomites	Sand and broken rock	6	0– 6
		Light grey dolomite	15	6– 21
		Dark brown dolomitic limestone	15	21– 36
		Light brown dolomitic limestone	50	36– 86
		Soft, grey, shaly limestone	15	86– 101
		Mottled, partly recrystallised dolomitic limestone	25	101– 126
		Soft, grey, shaly limestone	5	126– 131
		Mottled, partly recrystallised dolomitic limestone	25	131– 156
		Soft, grey, shaly limestone	5	156– 161
		Mottled, partly recrystallised dolomitic limestone	14	161– 175
	Pine Point limestones	Grey, shaly limestone	165	175– 340
		Hrad grey limestone	157	340– 497
		Brown, shaly limestone	33	497– 530
		Hard, black limestone	20	530– 550
		Brown, shaly limestone	30	550– 580
		Hard, grey limestone	20	580– 600
		Dark grey limestone	30	600– 630
		Grey, shaly limestone	50	630– 680
		Dark grey limestone	50	680– 730
		Light grey, shaly limestone	40	730– 770
Silurian	Fitzgerald dolomites	Light brown dolomitic limestone	20	770– 790
		Grey dolomitic limestone with gypsum	110	790– 900
		Gypsum	10	900– 910
		Grey dolomitic limestone with gypsum	70	910– 980
		Gypsum and anhydrite	65	980–1,045
	Red beds	Red shale with gypsum and salt	25	1,045–1,070
		Reddish stained salt	20	1,070–1,090
		Salt	30	1,090–1,120
		Red shale with salt and gypsum	20	1,120–1,140
		Gypsum	40	1,140–1,180
		Dark shale with gypsum and salt	20	1,180–1,200
		Salt	20	1,200–1,220
		Red shale with gypsum	40	1,220–1,260
		Red shale with gypsum and salt	120	1,260–1,380
		Reddish stained salt	10	1,380–1,390
		Gypsum and anhydrite	10	1,390–1,400
		Red shale with gypsum and salt	240	1,400–1,640
Precambrian		Red sandstone	20	1,640–1,660
		Brownish red sandstone	90	1,660–1,750
		Granite	56	1,750–1,806

The well was started in Presqu'ile dolomites at an elevation of about 15 feet above lake-level.

DESCRIPTION OF FORMATIONS

Precambrian

Rocks of Precambrian age are exposed on the northeastern shores of Great Slave lake and the islands lying to the south of them. Where examined, they were found to be granites and gneisses overlain by greenstone schists and metamorphics. On some of the îles du Large, coarse, white quartzites are

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abundant and occasional deposits of ferruginous limestones and some siderite were noted.

Robert Bell[1] reported sediments of probably Animikie or Lower Cambrian age on the eastern arm of the lake, but none were seen by the present writer.

Silurian Sediments

Slave river marks approximately the western boundary of the Precambrian shield and exposes at several places the contact between the Precambrian and the Palæozoic. The Precambrian floor is gently undulating and the Palæozoic sediments follow the undulations. The thicker sections expose gypsum beds under limestones and dolomites which carry a Middle Devonian fauna. The gypsum beds—best exposed on Peace river near Little rapids and in the escarpment at the salt springs west of Fort Smith—are interbedded with shaly limestones carrying Upper Silurian fossils.

In all the exposures on Peace and Slave rivers, Middle or Upper Devonian sediments immediately overlie the Gypsum series of Upper Silurian age and Kindle has proved that at Little rapids an erosional unconformity exists between these two series.

The following notes have been compiled from Camsell's report[2] upon the sections exposed on Peace and Slave rivers:

"The section exposed on Peace river shows as follows:

	Feet
Boulder clay and gravels of glacial origin	5 to 20
Limestone—argillaceous and sometimes sandy—fossils.	
Dolomites, fractured and broken	10 to 30
Gypsum beds	up to 50

The section is exposed on the banks of Peace river for about 18 miles in cliffs which rise 20 to 60 feet above the level of the river. The fossils from the limestones yielded the following species:

Spirorbis sp.
Atrypa reticularis
Schizophoria striatula
Cyrtinia curvilineata

These indicate an horizon of Middle Devonian age."

Kindle, working on the section in 1917, found a well-developed fauna of Silurian age in the Gypsum series and has proved that an erosional unconformity exists between these beds and the limestone series from which Camsell obtained his fossils. Kindle reports shaly members carrying fossils equivalent to the Ithaca phase of the Portage of New York lying "in situ" in erosional and solution cavities in the Gypsum series, and suggests that during Lower Devonian times land areas existed here which were subjected to erosion, and large sink-holes were formed in the Silurian sediments similar to those now found in the Palæozoic series near the salt springs west of Fort Smith.

On the west bank of Slave river opposite La Butte, Camsell obtained two sections. The northern one shows 10 feet of gypsum, thin-bedded and impure, overlain by 20 feet of a fractured and broken limestone similar to that on Peace river.

The other section shows as follows:

	Feet
Massive limestone—fossils	5
Pebbly limestone	10
Brecciated limestone, bituminous	6
Grey limestone, thin-bedded	10

[1] "Mackenzie District," Geol. Surv., Can., Sum. Rept., pt. H, Ann. Rept., new ser., vol. XII, 1899, p. 103 A.

[2] Camsell, C, "Salt and Gypsum Deposits in the District between Peace and Slave Rivers, Northern Alberta," Geol. Surv., Can., Sum. Rept., 1916.

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The beds undulate with dips up to 15 degrees and this, together with the fact that one of the beds has been fractured and brecciated, suggests the presence of a bed of gypsum beneath. Precambrian granites are exposed to the southeast within a few hundred yards.

The fossils collected from the upper bed of this section yielded the following species:

Atrypa reticularis
Martinia sublineata
Orthoceras—2 sp.

These indicate a Middle Devonian age, but the presence of gypsum in the northern section and the evidence suggesting its presence in the other imply that parts of the section at least are of Silurian age.

A number of good exposures occur on the banks of Slave river between Stoney and Caribou islands, 12 to 20 miles above Fitzgerald, and most of these sections show the contact betwen the Precambrian and the Palæozoic.

The Stoney Island section shows the following series:

	Feet
Limetone, light-coloured, massive, grading down into a dark grey, dolomitic limestone..	6+
Sandstones and conglomerates, arkose, granite. Coarse-grained, porphyritic..	8

The upper limestone contains a seam—one-half inch thick—of black, bituminous shale.

The Caribou Island section shows at the base a siliceous hornblende granite, jointed, fractured, and decomposed. Over this is an arkose about 10 feet thick of angular granite fragments becoming finer-grained at the top and passing gradually upwards into a dark grey dolomitic limestone which is exposed only beneath the drift for a thickness of 6 feet.

Camsell obtained no fossils from these sections, but Kindle found a Silurian fauna in both the Caribou and Stoney Island sections and refers the dolomitic limestones of both sections to a late Silurian horizon (verbal statement).

The escarpment at the salt plains on Salt river west of Fort Smith is from 150 to 200 feet high, but shows no complete section anywhere through its length. From fragmentary sections it is evident that the lower part of the escarpment is occupied by gypsum, whereas the top consists of a bed of dark grey, dolomitic limestone in which no fossils were noted. Both the gypsum beds and the dolomitic limestones are believed to be of Silurian age and to correspond in horizon to the gypsum cliffs at Peace point.

The Salt River escarpment extends northward down the west side of Little Buffalo river for a distance of about 35 miles and then appears to swing westward towards Buffalo river. Along Little Buffalo river it varies in elevation from 50 to 150 feet above the valley. Light to dark grey dolomitic limestones overlie the gypsum series. No fossils were collected from the gypsum beds, but the limestones yielded a fauna indicating a Middle Devonian horizon.

Below Fort Smith Palæozoic rocks are exposed at two points, but the outcrops are small. At Bell rock, a square, massive-looking cliff 7 miles below Fort Smith, a yellowish, brecciated dolomitic limestone is underlain by gypsum. A second exposure—on the point on the east side of the river just below pointe Ennuyeuse—shows 4 feet of thin-bedded, impure, grey gypsum underlying a fossiliferous, grey, shaly limestone, from which the following fossils, indicating a Middle Devonian horizon, were collected.

Favosites cf. hamiltonæ
Atrypa spinosa
Martinia cf. *meristoides*
Martinia cf. *sublineata*

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The occurrence of gypsum indicates that Silurian sediments immediately underlie the Middle Devonian.

Near Gypsum point on Great Slave lake, most of the outcrops are poor, though, at the point itself, a cliff about 20 feet high gave one section. On the south shore of the first point west of Gypsum point, angular blocks of dolomitic limestone 4 feet to 8 feet square are strewn along the beach, and though not actually in place can have come only from the immediate vicinity. The limestones, which are dark grey, very porous, and weather easily, are medium to fine-grained and highly fossiliferous, but the fossils are poorly preserved. The presence of *Pycnostylus guelphensis* places these limestones in the Upper Silurian, and suggests the correlation with the dolomite gypsum series, outcropping west of Fitzgerald.

At Gypsum point the following section was obtained:

	Feet
Thin-bedded, badly fractured, fine-grained, soft limestone quite arenaceous and brick red in colour. It is quite porous, contains no fossils, but has vugs filled with soft crystal faunules and weathers to a pebbly material..	4
Bed of a brick red gypsum with some sandy, brick red shales interbedded..	1½
Fissile, sandy shales, brick red in colour, and thin stringers of more or less pure gypsum. Shaly material shows ripple-marks, mud-cracks, and rain-pitting..	2
Massive, bedded, brick red, fine-grained sandstone, hard, and flaggy, containing angular clear quartz fragments. Bottom not exposed..	10

The lake beaches in the vicinity of the point and along the west shore of the north arm of the lake show the characteristic red colour of these beds.

The contact between these beds and the overlying grey dolomite limestone series mentioned above is not exposed on the lake shore. The log of the Imperial Oil Company's oil well at Nintsi point, previously given, shows a thickness of 275 feet of dolomitic limestones interbedded with gypsum and anhydrite, lying between the lower shaly limestones of the Pine Point formation and the Red beds.

In view of Kindle's determination of the Silurian age of the Gypsum series at Little rapids on Peace river and in the exposed sections along Slave river above Fitzgerald, and the apparent continuity of this series northward it is assumed in this report that gypsum horizons elsewhere noted indicate Silurian sediments, and they have been so mapped.

Middle Devonian

Middle Devonian sediments found in the area under discussion have been subdivided on lithological and palæontological evidence into three formations: in descending order, the Slave Point limestones, Presqu'ile dolomites, and Pine Point limestones. The palæontological evidence, as already shown, tends to correlate these respectively with the Manitoba limestones, Winnipegosan dolomites, and Elm Point limestones of the Manitoba section of Tyrrell and Kindle.[1]

Pine Point Limestones. Sediments of this formation outcrop in the neighbourhood of Resolution and Pine point on the south shore and on the north shore to the north and west of Kolon island and probably as far west as House point.

Near Resolution and on Mission island the sediments are thin-bedded, grey limestones, medium to fine-textured. In some beds the light grey, fine-

[1] Kindle, E. M., "The Silurian and Devonian Section of Manitoba," Geol. Surv., Can., Sum. Rept., 1912, p. 248.

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textured limestone is mottled with blotches of a darker grey, coarser-grained material. Some beds are very fine-grained, darker, and slightly bituminous. Small fissures and veinlets of pure white calcite are numerous. Fossils collected from this locality in 1920 yielded the following fauna:

Atrypa reticularis, var. *a*
Atrypa spinosa
Martinia sublineata
Cyrtina sp.
Productella spinulicosta
Paracyclas cf. *elliptica*
Pleurotomaria sp.
Euomphalus sp.
Proetus cf. *mundulus*

The abundance of *A. reticularis* var. *a* is conspicuous and the horizon may be conveniently termed the *Atrypa reticularis* zone.

In the vicinity of Pine point, thin-bedded bituminous limestones, grey to black in colour and in places very shaly, outcrop on a slight anticlinal structure. These beds though lithologically dissimilar belong on palæontological evidence to the same series as the soft grey limestones at Resolution, though somewhat higher in the series. Reference has already been made to the fossil collections made at this point in 1916. A further collection made in 1920 yielded:

Atrypa reticularis, var. *a*
Atrypa spinosa
Productella spinulicosta
Chonetes sp.
Liorhynchus sp.
Martinia richardsoni
Martinia sublineata
Stropheodonta sp.
Orthoceras sp.
Proetus cf. *mundulus*

An abundance of *Martinia richardsoni* is characteristic of this horizon and it may be conveniently called the *Martinia richardsoni* zone of the Pine Point formation.

The beds are mostly thin-bedded limestones, in some cases black and made up almost entirely of small brachiopods *(M. richardsoni and M. sublineata)*, and in others grey to blue-black in colour, containing numerous nodules which weather out characteristically, giving an uneven surface to the beds.

Near the crest of the hills south of Pine point and underlying massive dolomitic limestones carrying *Stringocephalus burtini* occur thin-bedded, shaly grey limestones carrying *Martinia richardsoni, Proetus* cf. *mundulus*, and other Pine Point fossils. These beds are assumed to represent the top of the Pine Point formation.

No exposures showing a measureable thickness of the Pine Point formation were seen either at Resolution or about Pine point. The estimated thickness given in the table of formations is based, therefore, on the log of the Nintsi (Windy) Point well.

In the valley of Little Buffalo river exposures north of the gypsum escarpment are few. At one point about 28 to 30 miles above the mouth, and just at the junction of Log-jam creek, the river cuts down into a highly fossiliferous limestone bed. The limestones are light grey in colour, thin bedded and interbedded with limy grey shale. Fossils collected included:

Favosites cf. *hamiltonæ*
Atrypa reticularis, var. *a*
Atrypa spinosa
Martinia sublineata
Paracyclas cf. *elliptica*
Pleurotomaria sp.
Euomphalus sp.
Proetus cf. *mundulus*

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This horizon is undoubtedly referable to the *Atrypa reticularis* zone of the Pine Point formation.

Limestones directly overlying gypsum beds on Gypsum creek, tributary to Little Buffalo river 30 miles north of the portage between Salt river and Little Buffalo river, yielded the following fauna:

Favosites cf. *hamiltonæ*
Cyrtina sp.
Productella sp.
Paracyclas sp.
Euomphalus sp.
Pleurotomaria sp.

This horizon also shows affiliations with the Pine Point formation.

On the north shore of the lake on a projection between Jones and House points, a low, wave-cut cliff situated about 75 feet above lake-level exposed the following section:

	Feet
Thin-bedded, light grey shaly limestones carrying between the bedding planes a fissile shale. Limestones are fine-grained, even textured, and weather to semi-round fragments.. ..	12
Blue-grey weathering limestones, thin-bedded and argillaceous. Some beds hard and flaggy and characterized by worm tracks, mud-cracks, and an abundance of crinoid fragments	4
Bottom not exposed.	

This section is closely comparable with some of the beds forming the top of the Pine Point formation exposed in the high land south of Pine point on the south shore.

Along House point and in the bay to the north no outcrops occur on the shores, but the lake beaches, in places forming distinct barrier beaches, show angular fragments of limestone very similar to that seen in the above section.

In the low hills to the west of Moraine point a steep escarpment facing east exposes thin-bedded shaly limestones interbedded with fissile shaly layers. The limestones are light grey in colour and weather to nodular and semi-round fragments. They appear to be the same as those exposed near House point.

No fossils were obtained from any of these exposures and correlation with exposures on the south shore is of necessity based upon lithological similarity.

On the mainland north of Kolon island and about House point occur a few outcrops of a thin-bedded, dark brown limestone. About one-quarter of a mile inland from the lake shore a low, wave-cut cliff 30 feet above water-level exposes the following section:

	Feet
Irregularly jointed, thin-bedded, grey limestone..	3
Even-bedded, fine-grained, hard, grey limestone..	3
Fossiliferous, irregularly jointed limestone interbedded with grey, shaly layers..	3½
Even-bedded, more massive, fine-grained light grey limestone..	2
Bottom not exposed.	

Fossils collected from this exposure yielded:

Martinia sublineata
Martinia richardsoni
Paracyclas lirata

They suggest correlation with the Pine Point formation of the south shore section.

Presqu'ile Dolomites. The Presqu'ile formation consists of hard, fine-grained bituminous dolomites and dolomitic limestones interbedded with softer, thin-bedded, grey limestones. Some beds are completely recrystallized dolomites. They are exposed capping the escarpment south of Pine point and about Presqu'ile point on the south shore, and abundantly about Nintsi

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(Windy) point and in the hills north of Sulphur bay on the north shore. In most exposures they are characterized by the presence of *Stringocephalus burtini* and may be conveniently termed the *S. burtini* zone.

The beds capping the escarpment south of Pine point are light brown, coarse-grained dolomitic limestones. They weather to a sandy-looking surface. Fossils collected included:

Favosites limitaris
Cyathophyllum sp.
Atrypa reticularis
Martinia sp.
Stringocephalus burtini

Farther south in the vicinity of the lead-zinc deposits the country rock is a coarsely crystalline, cavernous, and massive-bedded, white dolomite. The cavities are frequently lined with characteristic curved rhombohedral crystals of dolomite. Bitumen is entirely absent and no fossils were observed. Large sink-holes are numerous and expose a few feet of section in most cases. On lithological grounds these beds may be correlated with similar dolomites exposed about Nintsi point and there shown to be of the Presqu'ile formation.

On the middle islands of the Burnt Island group east of Pine point there are outcrops of a dolomitic limestone similar to those found about Presqu'ile point and carrying the following fauna:

Favosites limitaris
Cyathophyllum sp.
Atrypa reticularis
Atrypa spinosa
Martinia sp.
Stringocephalus burtini

The dolomitic limestones which outcrop just at water level about Presqu'ile point expose no great thickness of section. They are grey to white weathering porous dolomitic limestones. On fresh fracture they show a dark to grey-black colour and have considerable bitumen in the cavities. They are characterized by an abundance of fossils and are the type locality for the Presqu'ile series. The fossil collection made in 1916 has already been given. A further collection made in 1920 yielded the following species:

Aulopora sp.
Cyathophyllum cf. *caespitosum*
Cyathophyllum sp.
Favosites limitaris
Cladopora sp.
Actinostroma cf. *nodulatum* Nicholson
Stromatopora sp.
Atrypa reticularis
Atrypa spinosa
Chonetes sp.
Gypidula cf. *comis*
Spirifer sp.
Stringocephalus burtini

On the north shore of the lake at Brûlé point a low, wave-cut cliff exposes the following section:

	Feet
Thin band of wormy-looking, somewhat bituminous limestone.	½
White weathering, almost white, compact dolomitic limestone, composed largely of stromatoporoids	5½
Light cream weathering limestone composed largely of fossils embedded in a soft grey limestone	4
Massive-bedded, grey weathering, light grey, soft limestone	3
Thin-bedded, compact, hard, fine-grained dolomitic limestone, red brown to grey in colour, somewhat bituminous	2
Bottom not exposed.	

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Fossils collected from the above section included:

Cyathophyllum sp.
Favosites limitaris
Cladopora sp.
Actinostroma cf. *nodulatum* Nicholson
Atrypa reticularis
Martinia cf. *meristoides*
Pleurotomaria sp.
Callonema sp.

Mr. Kindle has stated that the presence of *Actinostroma* cf. *nodulatum* suggests the correlation of these beds with the Presqu'ile dolomites exposed on the south shore at Presqu'ile point. The discovery of *Stringocephalus burtini* or some other diagnostic fossils is needed, however, to strengthen the present available evidence of the correlation.

Similar beds are exposed all along the shores of Nintsi point and abandoned lake beaches of angular fragments of the limestones are found inland for some distance, many of them at elevations up to 150 feet above the present lake level. A low barrier beach of limestone shingle extends around the east shore of Nintsi point, enclosing a shallow, partly filled lagoon.

Where exposed near Nintsi point and Sulphur bay they are massive-bedded, generally coarsely crystalline, porous, and cavernous dolomites. The weathered surface is white to light grey and, the rock being hard and resistant to erosion, glacial action has well scoured the surface, leaving but little detrital covering. Well-developed glacial gouging and striæ indicate a general movement of the ice in a direction south 60 degrees west magnetic or north 85 degrees west astronomical. Fresh fractures frequently show a mottling of fine-grained, dark brown, bituminous, dolomitic limestone against a background of white, coarse-grained, partly crystalline dolomite. Large caverns and pores are numerous and are frequently lined with dolomite crystals and filled with semi-liquid bituminous matter.

The rocks are badly fractured in two general directions, north 75 degrees east and north 25 degrees east magnetic. The fissures are sometimes filled with a pure, clear, crystalline calcite, but more frequently are open and from them and from between the bedding planes of the dolomites issues a heavy petroleum which collects into oil and tar pools. Strong flowing, cold water sulphur springs frequently accompany the tar seepages, leaving deposits of sulphur and sulphur salts and occasionally carbonaceous salts of lime and magnesia.

Slave Point Limestones. Sediments of the Slave Point series outcrop on the south shore at Sulphur point and on Buffalo river near Mellor rapids. On the north shore they show on Slave point and on the tops of the hills north of Sulphur bay.

Buffalo river near Mellor rapids has cut through the overlying glacial drift and exposed low ramparts of grey weathering, light grey, fine-grained, and thin-bedded limestones that are slightly bituminous and carry numerous but poorly preserved fossils. Exposed surfaces of the beds are rough weathering and nodular owing to the more resistant qualities of the fossil material. Some beds show as distinctly bituminous lime shales weathering to light colours.

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East of Sulphur point a low, wave-cut cliff exposes the following section:

	Feet
Old lake beach of angular fragments of white weathering limestone	3
Grey-weathering, thin-bedded limestones and limy shales. Light grey, medium-grained, and hard. Shaly bands, weather pebbly and are argillaceous. Little or no bitumen	4½
Grey weathering, fine-grained, slightly more massive-bedded, light grey limestone. Contains some fossils and is slightly bituminous. Carries one thin band of fissile dark shale about the centre of section	2
Highly fossiliferous, porous, bituminous limestone, dark grey to brown in colour, medium-grained and hard	1½
Smooth-weathering, blue-grey to grey shales. Bituminous, and somewhat fossiliferous. Is quite limy and grades to thin-bedded limestones below water-level	½

No outcrops of sediments were noted between Sulphur point and High point, but the lake beaches are composed largely of small, angular fragments of slightly bituminous limestone similar to those found on Sulphur point and up Buffalo river. Strong-flowing, cold water sulphur springs occur on Sulphur point, on the shore east of High point, and in the banks of Buffalo river near the limestone outcrops.

On the north shore of Slave point thin-bedded, grey, fine to medium-grained limestones outcrop just at water-level but expose no thickness of strata. Weathered surfaces of the beds show a rough nodular appearance due to weathering out of the fossils.

On the crest of the hills lying to the north of Sulphur bay and overlying partly recrystallized dolomites a thin band of shaly limestones supplied the following fossils:

Atrypa reticularis
Atrypa spinosa
Rhynchonella cuboides
Cyrtina hamiltonensis
Schizophoria striatula
Murchisonia sp.

This is the most representative collection from the Slave Point series and the presence of *Cyrtina hamiltonensis* indicates that these sediments are probably equivalent to the Manitoba formation of the Manitoba section.

The limestones are exposed only as a capping and are mostly on the west slopes of the hills slightly below the crest, where they have been protected from glacial erosion by the more resistant qualities of the underlying dolomites. Dips as high as 12 degrees have been noticed in these beds, but they are believed to be only local and the average inclination probably does not exceed 40 feet to the mile.

Upper Devonian

Sediments of Upper Devonian age have been subdivided on lithological and palæontological evidence into the following formations, in descending order: Hay River limestones, Hay River shales, Simpson shales. On palæontological evidence Hay River limestones and shales appear to be equivalent to the Chemung formation, and Simpson shales to the Portage formation, of the New York section.

Simpson Shales. These shales, lying between the Hay River shales above and the Slave Point limestones below do not outcrop in the area under consideration. They are exposed, however, in the Mackenzie valley near Simpson and are considered to lie directly and conformably below the Hay River shales. They carry fossils analogous to those found in the Portage formation of New York.

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The shores of Great Slave lake west of a line drawn from High point to Slave point are characterized by low, sandy or muddy, marshy flats and appear to have been gouged out of the soft Simpson and Hay River shales by glacial action. It is assumed that most of this part of the lake is underlain by these Simpson shales and it has been mapped accordingly, the boundaries being approximate. The major portion of Buffalo River valley must also lie in these shales, but no outcrop of any sediments overlying the limestones near Mellor rapid was noted, the neighbourhood being heavily mantled with glacial drift.

E. M. Kindle[1] gives the following description of the Simpson shales near Simpson.

"On the northeastern bank of the Mackenzie river opposite Simpson, greenish grey clay shale outcrops in horizontal beds exposing a thickness of about 140 feet. This shale is without limestone bands and is almost or quite free from thin sandstone bands. It weathers to small flakes of fissile shale. Excellent exposures of this shale occur on both sides of the Mackenzie about 20 miles above Simpson. Along this portion of the river the banks expose a section from 50 to 150 feet thick. Fossils are scarce except in certain narrow bands of the shale which are not likely to be located without considerable searching. In the east bank of the river, about 5 miles above Rabbitskin river, fossils were found in a section exposing about 65 feet of greenish to bluish grey shales. These include the following species:

Cyrtina sp.
Buchiola retriostriata
Paracardium doris?
Entomis serratostriata
Entomis variostriata

This is a Portage fauna and indicates that the beds which it characterizes should be correlated with the Portage of New York.

"Neither the top nor the bottom of this formation has been observed, but the beds which immediately follow are well exposed in the Hay River section and carry the *Spirifer disjunctus* fauna. The latest beds preceding it which have been observed in the Great Slave Lake section are those outcropping at Sulphur point."

Hay River Series. Hay river, from near Grumbler rapids to its delta, has cut through a thick deposit of Upper Devonian sediments which on palæontological evidence may be correlated with the Chemung formation of New York state. Lithologically, the series may be divided into two members, the upper one being largely limestone strata and the lower one mainly made up of shale beds. Actually the two members grade into one another, the limestones at their base being interbedded with shaly layers and the shales showing frequent limy strata in their upper parts. For the purposes of this report the line of separation has been drawn at the base of the massive-bedded limestone member which causes Louise fall on Hay river. The upper member is called the Hay River limestones, and the beds below, the Hay River shales. The predominant weathering colour of the limestones is a light cream to buff; that of the shales is a dull blue grey.

[1] Kindle, E. M., "The Discovery of a Portage Fauna in the Mackenzie River Valley," Geol. Surv., Can., Mus. Bull. 29.

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Hay River Shales. The following section of the shales has been compiled from several sections taken at intervals along the valley of Hay river below Louise falls:

	Feet	
Bluish green, soft, fissile shales weathering to a grey, soft clay containing thin layers of highly fossiliferous limestone.. ..	42	
Thin-bedded, light grey weathering, grey, soft limestones, shaly layers between beds. Limestone composed largely of fossils.	20	
Blue green, soft shales, weathering to clay..	15	
Flaggy sandstone, with shaly partings. Sandstones show ripple-marks, crossbedding, and worm trails. Light yellow in colour..	14	
Fossiliferous, soft, grey, thin-bedded limestone..	8	
Blue grey, soft shales weathering to clay..	28	
Thin-bedded, fossiliferous, grey, argillaceous limestone. Thin beds of shaly material between limestone beds..	8	
Blue green, soft, clay weathering shales, carrying thin limestone bands which are highly fossiliferous..	105	
Thin-bedded, soft, greyish limestones carrying numerous fossils	8	
Blue green, soft shales weathering to grey calcareous clays.. ..	10	
Soft, shaly, rough weathering sandstone, argillaceous, and shows ripple-marks and worm trails..	12	
Blue green, soft clay weathering shales with thin bands of limestone carrying numerous fossils..	90	(aneroid)
Thin-bedded, grey, shaly, argillaceous limestone, soft and no fossils..	25	
Blue-green, soft clay weathering, calcareous shales..	15+	
Bottom not exposed.		

Hay river has cut a deep gorge-like valley through these shales for 45 miles from Louise fall to within a few miles of Great Slave lake. The shales being soft and easily weathered, the cut banks show steep talus slopes of soft, very plastic, grey, calcareous clays through which the more resistant limestone bands project to form limestone bluffs where the beds are of any great thickness. The shales carry no fossils, but the interbedded layers of limestone are highly fossiliferous and the clay talus slopes show abundant well-preserved specimens derived from them.

No other outcrops of the shales were seen, but on stratigraphic grounds it is assumed that similar sediments underlie the basin of Buffalo lake and parts of Mackenzie and Kakisa valleys. On Kakisa river at Lady Evelyn fall thin-bedded, light-coloured limestones can be correlated with the lower beds of the Hay River limestones that directly overlie the shales in the gorge below Louise fall on Hay river. It is probable, therefore, that Kakisa valley below the falls is underlain by shales that have been eroded by glacial action and are now covered by drift.

The massive-bedded Hay River limestones are not exposed on Buffalo river or about Buffalo lake, but probably occur from the base of Caribou Mountain plateau southward and it is, therefore, likely that shales now covered by glacial drift underlie Buffalo lake and probably the upper part of Buffalo valley.

Hay River Limestone. Limestones of the Hay River series are exposed in Hay valley for about 40 miles from near Grumbler rapids to the gorge below Alexandra and Louise falls. Limestones representing the same formation and containing a fauna similar to that of the Hay River series are also exposed on Peace river at Vermilion rapids.

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At the gorge on Hay river the following section is exposed:

	Feet
Massive, arenaceous, yellow to cream weathering, dark grey limestone	30
Thick and thin-bedded, light yellow to buff weathering, light grey, fine-grained limestone with shaly layers between beds.	62
Massive, light-coloured limestone containing numerous corals and some bitumen	16
Reddish brown, medium-grained, light weathering, thin-bedded limestones	12
Soft, thin-bedded, shaly, grey limestones and blue grey shales	6
Reddish brown, soft sandstone, calcareous and ripple-marked	7
Soft, blue grey, fissile shales, arenaceous at top, but generally very argillaceous giving clay talus slopes	47
Red brown, thin-bedded limestone	8
Thin-bedded, soft limestones and calcareous shales with limestone nodules, grey colours, and rough pebbly weathering	12
Thin-bedded, yellowish to cream weathering, red brown to grey, soft limestones	21
Bluish grey Hay River shales below.	

Between Grumbler rapids and Alexandra fall, limestones outcrop frequently in the valley, forming low ramparts and rapids but giving no continuous section of any thickness. The limestones are mostly light grey, thin-bedded, and frequently have shaly partings. Some beds, distinctly purplish or flesh-coloured, are mostly more compact and show no shaly partings. The uppermost beds, exposed just above Grumbler rapids, are grey-weathering, thin-bedded, shaly limestones consisting of limestone nodules embedded in soft calcareous clay shales. These nodules—principally fossil coral—weather out, giving a conglomeratic appearance to the outcrops. The thickness of the limestones between the upper beds of the section at the gorge and the outcrops of Grumbler rapids, estimated from the fall of the river between these two points and the observed general dip of the beds, is about 100 feet.

Limestones, lithologically similar to those at the bottom of the section in the gorge at Hay river, outcrop in the valley of Kakisa river causing a fall of 48 feet. They show here the following section:

	Feet
Grey to white-weathering, soft, thin-bedded, limestones with layers of soft, grey, calcareous shales between beds. Weathers to a rough nodular or pebbly appearance	15
Blue grey, soft, fissile shales	4
Thin-bedded, grey to brown, medium-grained limestones with shaly partings	22
Interbedded, grey, soft, thin-bedded limestones and blue grey, fissile, calcareous shales	26

The upper three members of this section seem to correspond to the bottom members of the Hay River section of the limestone, and the lowest member probably represents the gradation into the underlying Hay River shales.

During the summer of 1920 the Provincial Government of the province of Alberta drilled a well for salt at McMurray, Alberta. Professor J. A. Allan, of the University of Alberta, who was the geologist in charge of these operations,[1] gives the following section encountered in drilling.

[1] Allan, J. A., Second Annual Report of the Mineral Resources of Alberta, 1920, p. 104.

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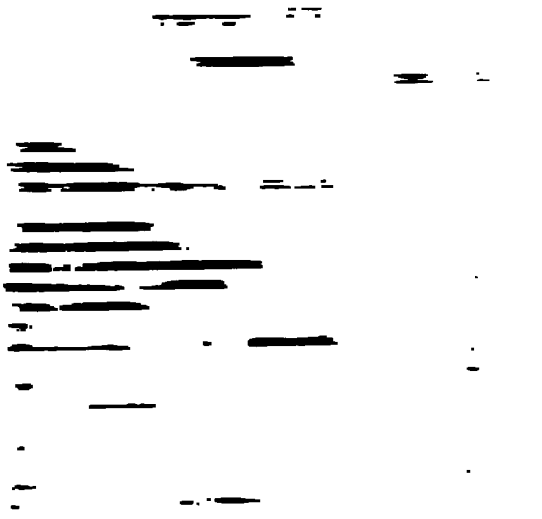

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"(2) The resemblance of this fauna to that obtained in the Upper Devonian as developed on Hay river, some of the fossiliferous bands being almost identical."

Warren also notes "the entire absence of the typical Middle Devonian fauna as developed on Great Slave lake."

Cretaceous

It is probable that Cretaceous sediments underlie most of the southern section of the area under discussion, but the known exposures are confined to the valleys of Peace and Hay rivers.

On Peace river above Vermilion rapids, soft, dark, fissile, marine shales of Cretaceous age outcrop in the banks of the river and represent parts of the Loon River shales of McConnell.[1] These have been well described by McConnell and McLearn[2] and no further mention need be made of them here.

On Hay river from the 6th meridian crossing to within a few miles of the first limestone outcrops near Grumbler rapid, shales, generally analogous to the Loon River series of McConnell's Peace River section, outcrop in numerous places where the river has cut banks in the valley walls. They are soft, dark, fissile, marine shales carrying numerous large spheroidal concretions and occasional hard, thin, ironstone bands. Selenite crystals are of frequent occurrence on talus slopes of the shale. Above Hay River outpost at the mouth of Meander river the shales are interbedded with thin, soft sandstones that may represent the Peace River sandstones of McConnell's section[3] on Peace river. Overlying the sandstones are soft shales, somewhat darker than the lower series and lacking concretions, which probably represent the basal member of the Fort St. John shales. But no fossil evidence was noted in any of the series and it is best not to attempt their subdivision or correlation, but to classify them as Cretaceous in age and probably for the most part representing the Loon River series of the Peace River valley.

The large area between Hay and Peace rivers, so far as is known, shows no rock outcrops. The plain between Peace river and Caribou mountains and on the west towards Hay river has the general appearance of an old lake basin of probably post-Glacial age. Caribou Mountain plateau and the small plateau of Watt mountains appear, by their elevation and stratigraphical relations, to represent outliers of the Cretaceous rocks of the Upper Peace River section farther southwest and probably contain representatives of the Peace River sandstone, Fort St. John shales, and Dunvegan sandstones of that section, overlain by glacial drift.

Pleistocene and Recent

Almost all the area shows marked effects of Pleistocene glaciation. The eastern part, underlain by Precambrian rocks, has little drift-covering and in many places exhibits unweathered rock surfaces that have been ground down and smoothed by the ice-sheet. The part underlain by limestones and shales is mostly covered by drift deposits such as boulder clays and contains numerous boulders of Precambrian rocks derived from the east. Sand and gravels of fluvioglacial origin occur only in small amounts. The surface of the boulder clay (ground moraine) is somewhat uneven, but is for the most part of low relief. In places, there are low, rounded hills, usually elongated somewhat in

[1] McConnell, R. G., "District of Athabaska," Geol. Surv., Can., Ann. Rept., new ser., vol. V, 1890, pt. D.

[2] McLearn, F. H., "Peace River section," Geol. Surv., Can., Sum. Rept., 1917.

[3] McConnell, R. G., "District of Athabaska," Geol. Surv., Can., Ann. Rept., new ser., vol. V, 1890, pt. D.

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the direction of ice movement, irregularly spaced and separated by swampy depressions. The rivers, wherever they cut across these hills, show banks frequently up to 100 feet high on the outside of the curve, and the boulders washed out of the drift collect in the river bed forming typical boulder rapids.

Glacial striæ are frequent and are specially well developed on limestone surfaces exposed by river or wave action. In the Precambrian rocks east of the lake, the striæ have a general trend south 22 degrees west, magnetic, or south 57 degrees west astronomical. On Buffalo river, they point south 16 degrees to 18 degrees west magnetic (south 52 degrees to 54 degrees west astronomical), and on Hay river above the falls south 25 degrees west magnetic (south 61 degrees west astronomical). Near Nintsi point striæ are well shown on the Presqu'ile dolomite and have a direction south 60 degrees west magnetic (north 85 degrees west astronomical). That this direction of ice movement was constant over a considerable part of the north shore is well shown by the character of the shoreline. In the deep bay to the west of Slave point and near the outlet of the lake all the points are approximately parallel to the direction of the striæ. Low boulder points are numerous in this bay and on Big island and have great accumulations of boulders derived from the Precambrian rocks. The same general conditions exist from Nintsi point north to Takgatea point. Unmistakable roches moutonnées are seen at several places, especially in the islands offshore between Resolution and Pine point, and in the Precambrian rocks to the east.

Striæ and the distribution of the drift show that the region was glaciated by an ice-sheet advancing from the Keewatin centre of glaciation and moving in a general west-southwest direction across the region. As the ice approached the upland known as Eagle mountains, west of Hay river, part of the sheet flowed down Mackenzie valley and part through the Buffalo and Hay valleys.

Terminal moraines occur in the Buffalo and Hay valleys and consist of low ranges of irregularly-shaped hills—200 to 300 feet high—that trend at about right angles to the striæ and cause—in the Buffalo valley—a dam behind which the waters from the north slopes of Caribou mountains form Buffalo lake. This moraine extends north to within a short distance of Great Slave lake. Two moraines were noted in the valley of Hay river, one between Watt mountain and Cutknife hills, the other between Caribou mountains and the hills west of Grumbler rapid. The low ridge of glacial drift between Watt and Caribou mountains, which forms the watershed between Peace and Hay rivers, appears to be an interlobate moraine formed between two lobes of the ice-sheet, one of which occupied Hay valley and the other the Peace valley.

During the retreat of the ice-sheet the northward drainage in Hay and Buffalo valleys was ponded between the retreating ice margin and the high land to the south, forming large, glacially-dammed lakes. Wide lacustrine flats, representing former lake bottoms, occur south of Buffalo lake. The wide plain near Vermilion was probably also a lake bottom. On both sides of Great Slave lake abandoned beaches as much as 200 feet above the present lake-level prove the existence of a once much larger lake. It is probable, as pointed out by McConnell,[1] that this lake owed its origin to depression of the land and has been partly drained in post-Glacial time by differential elevation of the land towards the east and northeast. The general direction of ice retreat was eastward, and it is improbable that the outlet of the lake basin down the Mackenzie valley could have been blocked by the ice at a time when the greater part of the basin was unoccupied by the ice-sheet.

[1] Geol. Surv., Can., Ann. Rept., vol. IV, 1888-89, p. 25 D.

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Recent Deposits

Alluvial (flood-plain) and delta deposits of Recent age occur in the valleys and at the mouths of most of the rivers. The rivers, though they are generally swift, are always widely meandering and are subject to great fluctuation in volume. Hence they are bordered in many places by alluvial flats or flood-plains underlain by crossbedded sands and silts. The rivers transport large quantities of sediment and at their mouths are forming deltas, the largest of which is at the mouth of Slave river. The sediment-laden waters of this river have gradually extended the delta out into Great Slave lake, filling a former embayment of the lake, and are now depositing their sediments into the west arm of the lake and gradually building land areas in it. This steadily growing delta is composed of crossbedded sands and silts. A fringe of excellent spruce borders the river banks and the interior is reported to be somewhat open prairie country with bluffs and copses of a light growth of spruce and poplar. Smaller deltas occur at the mouths of Hay and Buffalo rivers. The Buffalo delta is developed in an embayment which is cut off from the lake proper by a long series of old lake beaches through which the river has cut a single channel.

About 20 miles below Red river, Peace river on its south shore cuts for 3 miles into a bed of water-laid sand the top of which is mostly about 10 to 50 feet above high water.

Section opposite lower end of Long island:

	Feet	Inches
1. Forest bed and soil	1	
2. Brown sand	6	
3. Forest bed, etc.		6 to 0
4. Grey sand with pebble band in middle	1	
5. Hard sand within limy bands	1	
6. White marl		8 to 0
7. Grey sand with calcined roots	2½	
8. Marly sand		2
9. Grey, even-bedded sand partly covered	30	

No. 7 of above section shows roots that have extended through the marl of No. 6 and been covered by a thick tube of lime in No. 7.

About 125 miles above the mouth of Slave river cut banks of yellow sand 14 feet to 18 feet high are common for long stretches. They terminate abruptly against the ordinary alluvial banks and evidently represent a different and earlier set of deposits that are probably of lacustrine origin. Immediately below "Le Grand Detour" cut banks of this yellowish sand and gravel 40 feet high are exposed.

STRUCTURAL GEOLOGY

Bedrock in the region is gently monoclinal with dips of 1 or 2 degrees to the west or southwest. Except in the vicinity of Little rapids on Peace river where very abrupt anticlinal forms are developed, no dips exceeding 6 degrees were observed. The eastern edge of the area shows the margin of the Precambrian protaxis and the Palæozoic sediments laid down on this floor follow the irregular relief of the protaxis and thicken to the westward as the distance from the Precambrian rocks increases.

The tendency of the Palæozoic sediments to conform to the underlying Precambrian floor is particularly well shown on Slave river a few miles above Fitzgerald, where the stream has cut through a projecting arm of the Precambrian, exposing a gently rolling erosion surface. Coarse-grained, arkose

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material, derived by weathering of the Precambrian floor, overlies these rocks, and is covered by Silurian or Devonian limestones that gently dip away from the sides of steeply rising knobs of Precambrian rocks, thus conforming to their rolling and irregular surface.

The sedimentary rocks range in age from Upper Silurian to Lower Cretaceous. On Peace river, Kindle finds an erosional unconformity between Upper Silurian and Upper Devonian beds, but on Great Slave lake a thick series of Middle Devonian sediments is found under the Upper Devonian, indicating variations in the extent of the early Palæozoic seas. At no point in the area were distinct Lower Devonian beds found and it is probable that they are not represented.

On Hay river above the falls, and on Peace river above Vermilion chute, Cretaceous shales overlie the Upper Devonian limestones. The contact is not exposed in the area examined, but where seen in the Athabaska valley shows as an erosional unconformity.

Throughout the district, the drift interferes with an accurate study of the structural features. Outcrops are mostly small and far apart, being confined, as already stated, to the valleys and lake shores.

On Hay river above Alexandra falls and on Buffalo river at Mellors rapid the limestones show local anticlinal folding with gentle dips, but the surface is uncovered only in the immediate valley bottom and the superficial extent of the folds was not determinable.

On the shores of Great Slave lake structural features are obscured largely by the limestone gravels formed by ice and wave action on the exposed surfaces of the sediments. Here again local inclinations are often greater than the general dip. They appear to be very local, however, and seldom exceed 6 or 8 degrees from the horizontal. They often show dips in all directions within a radius of a few hundred feet.

The eastern edge of the district lies close to an eastern shore-line of the Palæozoic epicontinental seas. Epirogenic movements were gently oscillatory and the sea invasions seem to have come largely from the north and west. The seas were frequently shallow as shown by the brecciation of much of the limestones, particularly where they immediately overlie the Gypsum series as at Bell rock below Fort Smith. The absence of coarse detrital material in any of the sediments indicates a low-lying shore-line to the east, from which little or no rock-forming material was being derived except that in solution. This is shown in the exposures on Slave river above Fitzgerald where the arkose material overlying the Precambrian granites and gneisses is made up of residual decomposed granitic and gneissic fragments embedded in a calcareous matrix.

LOCAL DOMING

On the lake shores wherever outcrops occur at or near water-level a warping of the strata into small local domes is evident. These have diameters of from 100 to 200 feet and have dips seldom exceeding 8 degrees. In a few cases where shelving outcrops occur, soundings were taken at some distance from the shore and it was found that the shelves break off into deeper water forming cliffs similar to those above water-level on the north shore. It was also found that wherever the thin-bedded limestones outcrop at water-level the dip of the strata is apparently towards the lake.

The domes may be due to the transformation of anhydrite beds at depth into gypsum, with consequent increase in volume. This theory is supported in several cases, particularly at Sulphur and Nintsi points, by the presence of large sulphur springs in the vicinity, though no springs were found on any of

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the domes. Moreover, the massive-bedded dolomites exposed in spite of heavy glaciation at the tar springs on Nintsi point distinctly show doming which could not have been formed by the action of lake ice.

SLAVE AND PEACE RIVERS SECTIONS

On Slave river between Stoney and Caribou islands 12 to 20 miles above Fitzgerald, sections are exposed showing the contact between Palæozoic sediments and the underlying Precambrian floor.[1] The sections show coarse-grained, porphyritic, and siliceous hornblende granites, jointed, fractured, and decomposed, overlain by conglomerates and arkose about 10 feet thick and these in turn by dark grey, dolomitic limestones. The beds have a slight dip and occupy depressions in the old granite surface, depressions which have a depth of as much as 50 feet, suggesting that the relief when these beds were deposited was not very different from the present relief in the adjacent Precambrian area.

On Peace river near Little rapids and Peace point, cliffs 20 to 60 feet high rise above the level of the river. As reported by Camsell[2] the lowest bed exposed is of gypsum of variable thickness but not over 50 feet. The next overlying bed is a fractured and broken dolomite from 10 to 30 feet thick above which is an argillaceous, sometimes sandy, limestone containing fossils.

"The beds undulate in both sharp and gentle folds and in one place are bent into a sharp anticline with dips on either limb of 60 degrees. The strike of the folds is not constant but varies widely.

"In seeking for the cause of such a disturbed and irregular structure it was evident that the disturbance of the beds could not possibly be connected with any orogenic movement of great magnitude, but was local in its effect and apparently confined to these particular beds. Certainly there is no evidence elsewhere throughout the region of the great plains, of the operation of mountain-building forces producing such sharp folds as those indicated by dips of 60 degrees. The solution of this problem was found in the gypsum itself. At certain of the outcrops of gypsum, rounded cores of anhydrite were noted in the gypsum. These cores showed a scaly rim of gypsum where the anhydrite by the absorption of water was altering to gypsum. At other localities, thin beds of anhydrite are interbedded with the gypsum. These facts suggest that some of the layers of gypsum, if not all of them, were originally anhydrite which by the accession of two molecules of water became altered into gypsum. In process of this alteration there would be an increase in the volume of the beds by 33 per cent. This increase causes horizontal as well as vertical expansion. The horizontal expansion results in folding of the beds and both together would probably cause the fracturing and brecciation of the overlying beds of limestone, for almost everywhere that the gypsum and the overlying limestone beds were exposed, the limestone was found to be so fractured and brecciated, in places for only a vertical distance of 10 feet, but in other localities for as much as 40 feet."

GREAT SLAVE LAKE SECTION

The Palæozoic sediments are frequently exposed from Resolution west towards Presqu'ile point. From Presqu'ile point to High point exposures are confined to the points and are mostly situated from 8 to 12 miles apart. West

[1] Camsell, C., "Salt and Gypsum Deposits in the District between Peace and Slave Rivers, Northern Alberta," Geol. Surv., Can., Sum. Rept., 1916.

[2] Camsell, C., "Salt and Gypsum Deposits in the District between Peace and Slave Rivers, Northern Alberta," Geol. Surv., Can., Sum. Rept., 1916.

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of High point the lack of exposures suggests that the lake basin is here gouged out of the soft, easily weathering clay shales of the Hay River series. The bedrock is essentially flat-lying with a westerly dip not exceeding 50 feet to the mile, and this condition appears to be uniform throughout the whole of the western part of the lake basin.

At Pine point and in Resolution bay the exposures indicate a gentle anticlinal tendency, the apex of the anticline being in the vicinity of the point itself. The limbs of the fold do not show except by fossil evidence and the lithological similarity of the rocks found on Burnt islands to the east and at Presqu'ile point. About Resolution and Mission island the *Atrypa reticularis* zone of the Pine Point series is well developed and the same horizon is shown on Little Buffalo river, about 30 miles above its mouth. The middle islands of the Burnt Islands group show Presqu'ile dolomites carrying *Stringocephalus burtini*. The remainder of the Burnt Island group and the shores of the mainland from near Twin islands to a point west of Deadman island show the Pine Point sediments. The escarpment south of Pine point is capped by Presqu'ile sediments overlying upper members of the Pine Point series and the Presqu'ile is again exposed at water-level about Presqu'ile point to the west. Sediments very similar to the Presqu'ile series occur on the mainland for about 2 miles west of Little Buffalo river.

West of Presqu'ile point no structure other than the gentle monoclinal conditions already referred to is observable along the south shore. From Sulphur point the Slave Point limestones appear to continue to west of High point where they disappear and are overlain by the soft Simpson or Hay River shales. The character of the shore west of High point suggests the presence of these soft, easily weathering shales and they apparently continue to Mackenzie river.

Middle Devonian limestones and dolomites are exposed about Slave and Nintsi points. Coarsely crystalline and porous dolomites of the Presqu'ile series, abundantly exposed about Nintsi point and north of Sulphur bay, are badly fractured and fissured and show seepages of a heavy petroleum. Strong flowing cold water sulphur springs are numerous and salt water accompanies the petroleum.

North and east from Nintsi point soft, shaly limestones, lithologically similar to the upper members of the Pine Point series, are exposed in places about Jones and House points and as far north as Moraine point, where the shore eastwards becomes low and swampy and shows no outcrops. This part of the lake basin has probably been eroded in these soft shaly members of the Pine Point series. At Ketsikta point, lower members of the Pine Point series, exposed at water-level, are followed to the east by underlying dolomites and gypsum beds of Silurian age.

The north shore section shows no evidence of structural conditions similar to those indicated about Pine point to the south, but the sediments appear to lie in normal sequence with a slight dip to the west or southwest.

ECONOMIC GEOLOGY

GENERAL STATEMENT

The Precambrian rocks to the east are largely granites and granite gneisses and are not likely to be rich in metalliferous deposits. In a few places there are patches of older metamorphic greenstones, quartzites, conglomerates, and occasional limestone sediments. Near the contact between these and the granites, fissures occur showing copper and iron stainings, but are usually

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small and show no evidence of larger deposits occurring at depth. Gold has been reported in fissures in the neighbourhood of Yellowknife river northeast of the map-area, and in 1916 copper with gold and silver was reported from Caribou island at the entrance of the east arm of the lake. A large body of iron ore has been reported from the îles du Large, but though the writer spent several days amongst these islands during the autumn of 1916, he found no evidence of this deposit nor was his compass in any way affected by local attraction.

The Palæozoic sediments contain deposits of possible economic importance of lead, zinc, petroleum, salt, gypsum and brick clay, sulphur, and potash. A deposit of galena and blende has long been known in the region south of Pine point. Claims have been staked, allowed to lapse, and been restaked since the deposit was first discovered by a party of prospectors on their way to the Klondike in the middle nineties. The salt deposits on Salt river and the salt plains west of Fort Smith have been known ever since the white man first visited the country and have supplied the demand from all the northern part of Mackenzie basin. Gypsum occurs with the salt at the salt springs and outcrops at various places along Slave river and particularly on Peace river near Little rapid. At Nintsi point seepages of a heavy petroleum occur in numerous places and on evaporation of the volatile constituents leave tar pools which supply pitch for local needs. The thick beds of Hay River shales on Hay river weather to a plastic clay which is used as a wall-wash for the Indian houses at Hay river and has been proved to burn to a good grade of building brick. Strong-flowing sulphur springs occur at numerous places; these by depositing sulphur may be of economic importance. Potash is to be looked for in the vicinity of the gypsum and salt beds. Analyses of spring waters from near these beds show a potassium content insufficient to be profitably exploited. Better results are reported of waters from between Fort Smith and Peace point.

LEAD-ZINC DEPOSITS

About 10 miles south of Pine point and about 250 feet above the lake a flat-lying, crystalline dolomite outcrops in places over an area of several square miles. The dolomite is grey, weathering white, and quite coarsely crystalline. Fresh fracture shows a porous structure and many cavities in which typical curved rhombohedral crystals of dolomite occur. The general lithological character of the rock is identical with that of the Presqu'ile dolomites on Nintsi point, but bituminous matter and sulphur springs are here absent and no fossils were obtained by which correlation could be confirmed. Large sink-holes 10 to 20 feet deep and as much as 200 feet in length are numerous.

At one place a slight folding of the strata into a monocline or broad anticline is developed. The western limb only is exposed and has a dip of 5 degrees to the north and a strike of north 20 degrees east magnetic or north 55 degrees east astronomical. This fold strikes transverse to the axis of the Pine Point anticline. Its crest is badly fractured and fissured and there the dolomites are impregnated with considerable quantities of galena and some sphalerite. Exceptionally large sink-holes occur just east of the crest of the fold and expose shallow sections of the impregnated dolomites.

The general structure shows a massive bedded dolomite. Mineralizing solutions have percolated along the bedding planes and impregnated the overlying beds. In some cases galena is evenly disseminated throughout a bed, but usually is more abundant in the lower 18 or 20 inches. Some of the beds are more highly impregnated than others. Sphalerite always acompanies the

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galena and in places is the predominant ore mineral. In the limited exposures examined, sphalerite appears to increase with depth. Small amounts of pyrite or marcasite are sometimes present, usually encrusting poorly defined and undeterminable fossils.

The origin of the ores was not evident. The ore-body appears to be a replacement of the dolomite by mineralized solutions which entered along fissures. At one point situated a few hundred feet southeast of the crest of the fold, a thin fissure was traced for a few feet and then lost under the surface till. It shows as a vein a few inches across, in some places completely filled with a coarsely crystalline galena and in others showing a banded structure of calcite, zinc blende, and galena deposited in the order shown. Pyrite was absent in the vein-filling where seen, but shows in small quantities in the impregnated dolomites.

The calcite forming the gangue of the vein is white to grey-white and very fine-grained, almost lithographic in character. It is frequently impregnated with fine, hair-like lines of galena spreading from a common point into a fan-like structure. This point is the end of a thin fissure in the calcite which though not metalliferous connects with the more massive galena filling in the interior of the vein. The sphalerite is usually dark brown and has a botryoidal structure at its contact with the galena. It, also, is somewhat mixed with coarse galena. The galena fills the central parts of the vein, is massive, usually coarsely crystalline, and carries but little sphalerite.

The dolomite forming the country rock is very coarse and porous, carrying numerous vugs and cavities which in places have been filled by the mineralizing solutions. These show concentric structures and a deposition of the minerals in the order, calcite, zinc blende, galena. Galena usually occupies the centres of the cavities or shows thin fissures connecting the centre with the cavities.

On exposed surfaces secondary oxides of zinc and lead are common, and in places secondary sulphides occur in stalactitic and botryoidal forms.

Claims have been staked and some prospecting work has been done, but very little in recent years. The prospect pits are all badly caved now and no data were obtainable from them.

The mineralized area appears to be confined to the anticline where fissuring has allowed the mineralizing solutions access to the dolomite. Since the ores are non-argentiferous the value of the deposit does not seem very great.

BITUMEN AND PETROLEUM

The determination of the possibilities of an oil field near Great Slave lake was one of the main objects of the exploration. The Athabaska and Peace River districts to the south have been prospected for oil and several wells sunk, though with little success. Small flows of oil and strong flows of gas have been struck in several places, the most promising to date being near the town of Peace River. Here in 1917 the McArthur well No. 2 struck strong gas flows and obtained a production of about nine barrels of heavy oil a day.

The oil appears to come from an horizon in the Cretaceous not far above the Devonian and it was hoped that a study of the Devonian sediments exposed to the north would determine whether this oil originates in the Devonian sediments or in the overlying Cretaceous.

A well was sunk at Vermilion chutes in Devonian sediments and reached a depth of 850 feet when drilling difficulties caused the hole to be abandoned. No oil or gas was encountered.

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On the shores of Great Slave lake practically all the outcropping limestones are more or less bituminous and some on fracture give a distinct seepage of heavy petroleum.

At Nintsi point the massive-bedded Presqu'ile dolomite is highly impregnated with oil. Several tar pools are formed where this oil, on reaching the surface, has lost its more volatile constituents, partly by evaporation and partly by absorption by the mosses and soil. Where seepages occur on bare rock, oil pools collect in the hollows and crevices. The dolomite is white or grey weathering and coarsely crystalline. Fresh fracture shows a cavernous and porous structure, the cavities mostly holding considerable quantities of bituminous material. In places it has the appearance of a mixture of a dark brown bituminous crystalline magnesian limestone and a more coarsely crystalline white dolomite. The rocks are badly fractured and fissured and show distinct evidence of local doming. The tar and oil pools occur along these fissures and along the bedding planes. Cold water sulphur springs are numerous in the vicinity of the oil seepages.

At Presqu'ile point and on the islands east of Pine point, cavernous and porous dolomitic limestones of the Presqu'ile series also show bituminous and oily matter in the pores and cavities, and the Pine Point series of shales and shaly limestones outcropping at Pine point and known to underlie the Presqu'ile series are highly charged with bituminous matter.

The Presqu'ile dolomites appear to be the principal oil-bearing horizon and as these are exposed at the surface on the limb of the anticline the possibilities of an oil field of great value near the lake are slight.

For a productive oil field four particular geological features are necessary.

(1) A supply of liquid oil of sufficiently low viscosity to flow through the pores and cracks of the oil sand at the temperature obtaining where the oil is found.

(2) A container porous in itself, as in the case of a sandstone, or made so by fracturing or other changes as in the case of a shale, limestone, chert, or dolomite.

(3) An impervious capping, usually a shale, over the container, for imprisoning the oil until it is released by the drill.

(4) A rock structure favourable for the accumulation of the oil in reservoirs from which it may be obtained when tapped by the drill.

Two, and possibly three of the conditions are fulfilled in the area about Great Slave lake. The structure sections, at least at Pine point, show proper anticlinal conditions, though of a gentle order, the Presqu'ile dolomites are sufficiently porous to act as a container, and the oil pools on Nintsi point show that some petroleum is present in the dolomites. The container is, however, exposed at the surface and the oil content of this structure has probably long ago escaped.

Underlying the dolomites are the Pine Point series of limestones and limy shales, which, where exposed on Pine point, appear to be sufficiently compact to act as a capping over any possible oil-bearing horizon existing below these sediments. But the sediments underlying the Pine Point series on the north shore do not look to be suitable for containing oil, although the immediately underlying Fitzgerald dolomitic limestones are somewhat porous.

Undoubtedly the Presqu'ile dolomites are the best container for oil and if an impervious capping can be found overlying these in a district structurally suitable, the conditions would at least warrant exploration with the drill.

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Hay river gives an excellent section through the sediments overlying the dolomites. This section shows 340 feet of a soft, fissile clay shale overlain by 200 feet of rather massive limestones. Between the shales and the dolomites are 250 feet more of soft shales and 200 feet of a thin-bedded shaly limestone. This 790 feet of shaly material would prove an ideal capping for an oil field.

The well drilled at Vermilion chutes by the Peace River Development Corporation is the only one which has penetrated the Devonian sediments. The log of the well is given below and for purposes of comparison a summary of the Hay River-Great Slave Lake section is given with it. It is to be noted that the fossil evidence shows the limestones outcropping in the vicinity of Vermilion chutes to be analogous to the upper limestones found on Hay river.

Hay River–Great Slave Lake section		Well log at Vermilion chutes, Peace river	
	Feet		Feet
Upper Devonian:			
Hay River limestone series			
Limestone	200+ –	Limestones	129
Clay shale	49	Clay shales	40
Limestones	51	Limestones	131
Hay River shale series			
Clay shales with limestones	400		
Simpson shales	250+ –	Clay shales	550
Middle Devonian:		Depth of well	850
Slave Point limestone	200+ –	Flooded by salt water and abandoned.	
Presqu'ile dolomites	375		
Pine Point limestones	595		
Upper Silurian:			
Fitzgerald dolomite limestones	275		
Red beds	595		
Precambrian:			
Granites and metamorphics			

The well driller reports oily or bituminous matter in the limestone strata in sufficient quantity to cause stickiness and somewhat hinder drilling operations, though not in sufficient quantity or fluid enough to give a flow. It is to be regretted that it was found impossible to continue the well to greater depths. Another 200 feet or 300 feet might have penetrated the dolomites and proved the value of that horizon as an oil container at this locality.

Kindle's section on Peace river near Little rapids, however, shows that, there, the Upper Silurian gypsum beds are unconformably beneath the shale series and the porous Presqu'ile dolomites are absent. Whether or not similar conditions hold at Vermilion chutes, 100 miles farther west, cannot be stated until another well is drilled in the vicinity.

The oil occurrences at Nintsi point appear as seepages on the exposed surfaces of the oil-bearing horizon and, therefore, if an oil field is to be located in this horizon it should be looked for to the west of the outcrops where it will be under the suitable cover of Hay River or Simpson shales.

A possible explanation of the oil seepages at Nintsi point is worthy of notice. The sulphur-bearing waters rising from below, carrying considerable quantities of calcium and magnesium salts and percolating through the overlying thin-bedded, dolomitic limestones change them to crystalline magnesium

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limestones and dolomites. In the process bitumen is set free and forced into the cavities in the dolomites or through the fissures developed during dolomitization, to the surface, to form the tar and oil pools.

The field facts upholding this explanation are:

Certain parts of the beds are not yet completely changed to dolomite, but are made up of a coarsely crystalline white dolomite mixed with a more finely crystallized, dark brown, bituminous, dolomitic limestone. No distinct line of separation exists between the two phases and there is a gradation of one into the other.

In places the outlines of fossil remnants are distinctly visible. In the neighbourhood of Sulphur bay to the north of Nintsi point similar dolomites occur and, there, distinct fossils are numerous, though they show a partial recrystallization into curved rhombohedral crystals of dolomite.

No natural gas accompanies the oil seepages.

If the above is the true explanation of the conditions at Nintsi point, it would tend to show that the oil seepage there represents only local conditions and the possibility of a commercially economic oil horizon in the Presqu'ile dolomite is small. On the other hand, the oily matter in the cavities in the Presqu'ile dolomites exposed at Presqu'ile point and Burnt islands indicates much more extensive oil-bearing conditions and tends to prove that the structural conditions are the deciding factor in the concentration of the oil. Which explanation is the correct one will only be proved when a well is drilled into the dolomites through the overlying impervious capping. It is the writer's opinion that the oil seepages at Nintsi point are probably the product of the joint action of both conditions.

Regarding the character of the oil, the following table gives analysis of a sample collected at the seepages and for comparative purposes an analysis of a sample from one of the wells on Peace river near Peace River crossing.

Comparative Analyses of Oils from Great Slave Lake and Peace River

—	Great Slave lake	Peace river
Sp. gr. crude at 15·5° C	0·957	0·984
Sulphur in crude	1%	4·9%
Cal. value (B.T.U.) crude	18070	17520
Oil distillate by vol	64·5%	73·9%
First drop	178° C.	140° C.
Gasoline and kerosene (to 150° C.)	—	2%
Illuminants (150° to 300° C.)	23% of distillate	32·5% of distillate
Lubricants and residue	77% "	64·5% "

It has already been noted that nearly all the limestones outcropping on the lake shore are bituminous. At Nintsi (Windy) point, thin-bedded, dolomitic limestones, porous and cavernous and highly fossiliferous, apparently overlie the massive, crystalline dolomites that may be the product of secondary alteration of the dolomitic limestones. Cold sulphate water springs occur in the crystalline dolomites and though unfortunately no sample of the waters was taken for analysis, a partial analysis of salt encrustations from near one of the springs showed abundant sulphates and carbonates of calcium with

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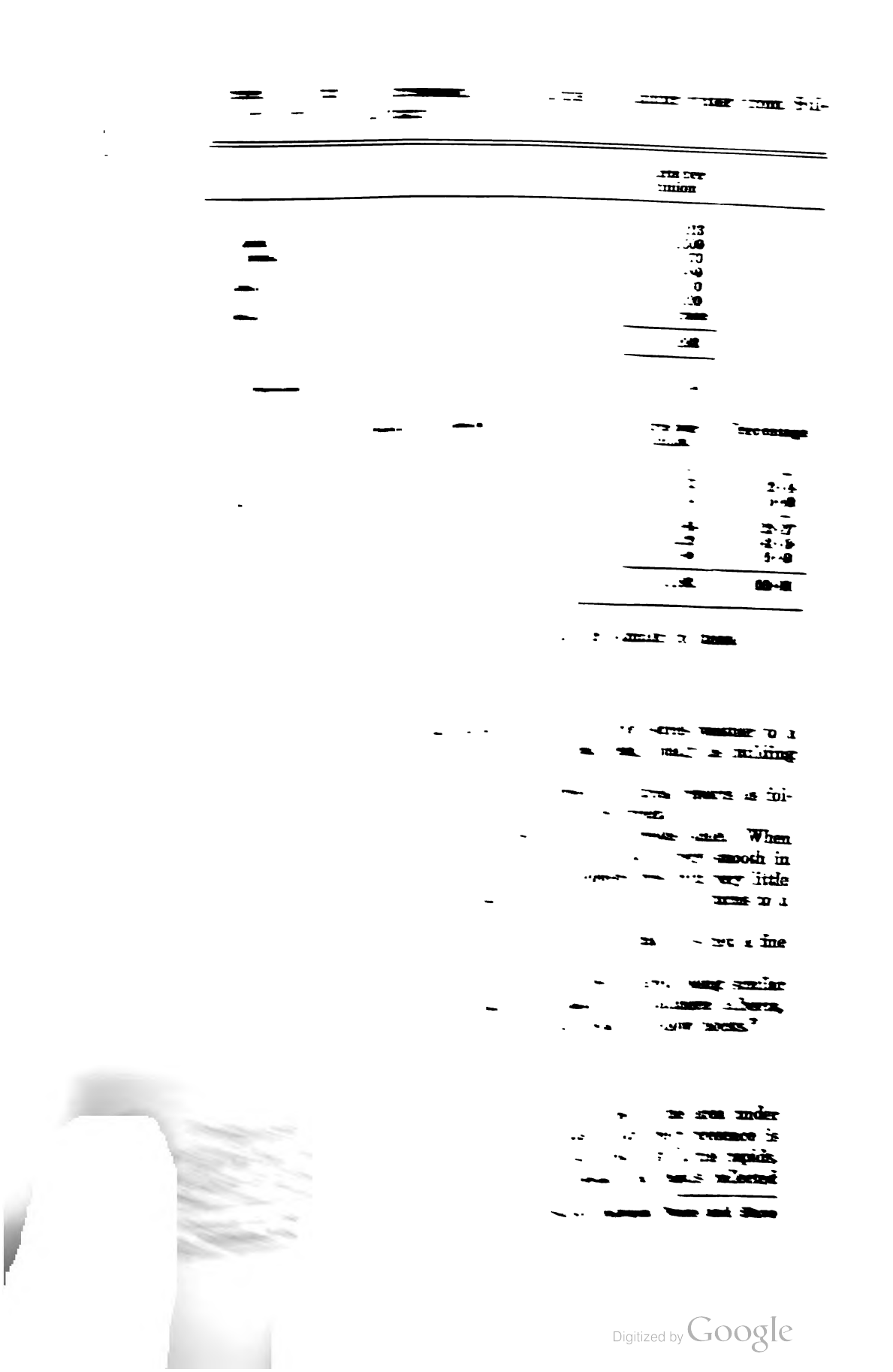

from shaly or limy beds in the series indicate an Upper Silurian age. At Gypsum point, limestones carrying Upper Silurian fauna overlie a series of red arenaceous limestones carrying gypsum and it is assumed that the gypsum is characteristic of the Silurian in the area and that the fauna is indicative of Silurian sediments.

Reporting on the gypsum deposits between Peace and Slave rivers, Camsell[1] says, in part:

"At almost all the outcrops of Palæozoic rocks in the area an important deposit of gypsum occurs. How much of the region is actually underlain by gypsum it is difficult to say, but the area must be very great and can probably be measured in hundreds of square miles.

"On Peace river gypsum is exposed on both banks of the river almost continuously for a distance of 15 miles, or from Little rapids at a point 5 miles below Peace point. The exposed thickness varies from a few feet up to a maximum of 50 feet, the latter occurring on the south side of the river at the foot of the rapids. The gypsum is usually white and massive, but in places it is earthy and thin bedded or holds narrow bands of dolomitic limestone. Selenite is rare, but thin veins and beds of satin spar are common. Anhydrite is occasionally present in rounded nodules or thin beds. Overlying the gypsum is a fractured and broken bed of limestone, but frequently this has been removed by erosion and glacial drift 5 to 15 feet thick forms the only capping."

Camsell estimates at least 217,000,000 tons of gypsum in the vicinity of these Peace River outcrops. Much of this tonnage is favourably situated for mining on account both of its location and the thin overburden of drift. No attempts have been made to work the gypsum and no claims have as yet been taken up.

Camsell's section at La Butte on Slave river shows a 10-foot bed of a somewhat earthy gypsum, thin-bedded and white, grey or bluish in colour. Seams of selenite and satin spar traverse the beds, which are overlain by some 20 feet of brecciated limestone.

Gypsum is said to underlie the brecciated limestones at Bell rock near Fort Smith, and outcrops on Slave river immediately below pointe Ennuyeuse where a thickness of about 4 feet of thin-bedded, impure gypsum is exposed near water-level.

In the escarpment at the salt plains west of Fort Smith gypsum exposures up to 40 and 50 feet are reported by Camsell. The gypsum is thin bedded, white or greyish, and disposed in horizontal beds. Occasional narrow beds of anhydrite or dolomite are interbedded with the gypsum. Northward the gypsum appears to thin and is overlain by beds of grey crystalline dolomite.

Regarding the extent of these deposits, Camsell says:

"The escarpment is known to extend more or less continuously from a point some 8 miles southwest of Fitzgerald in a sinuous line northwestward for about 40 miles, or beyond Little Buffalo river. Since the escarpment is probably caused by erosion where hard resistant beds overlie softer and more soluble strata, it is reasonable to suppose that as the strata of the escarpment are horizontal, gypsum will be found to occupy the base of the escarpment throughout the greater part of its length. This suspicion is borne out by the character of the surface on the top of the escarpment, which is broken and pitted with sink-holes in a way characteristic of a gypsum region."

At Gypsum point, on Great Slave lake, thin beds of flesh-coloured, impure gypsum are interbedded with brick-red, arenaceous, thin-bedded limestones.

[1] Camsell, C., "Salt and Gypsum Deposits of the District between Peace and Slave Rivers, Northern Alberta," Geol. Surv., Can., Sum. Rept., 1916.

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Thin seams and stringers of pink satin spar traverse the gypsum beds and in the arenaceous limestones casts of large salt crystal "funnels" are numerous. The gypsum as exposed is too thin-bedded and impure to be valuable, but its presence here indicates the extent of gypsum deposits in the Silurian sediments.

The well of the Imperial Oil Company drilled at Nintsi point passed through 65 feet of gypsum and anhydrite in one bed and 10 feet in another, and the grey dolomitic limestones associated with these deposits appear to carry other numerous stringers or thin beds. The red beds directly following these dolomitic limestones are also highly gypsiferous and carry several deposits of appreciable thickness as well as considerable quantities of salt.

SALT

Rock salt is to be looked for associated with gypsum, and is reported in the logs of most of the wells drilled in the region. The reported occurrence of thick beds of salt encountered in wells drilled for oil in the vicinity of McMurray led the Provincial Government of Alberta to sink a well for salt at McMurray during the summer of 1920. The log of this well has already been given.

Allan gives the following analyses of samples of salt from the core of this well:

Analyses of Rock Salt from Drill Core

—	1	2	3	4
Water, soluble	53·78	–	–	–
Insoluble	46·32	0·24	0·46	0·30
Analyses of water, soluble				
Calcium sulphate	1·94	4·74	0·90	2·78
Sodium chloride	97·28	94·78	98·46	96·53
Ignition loss	0·40	0·	–	0·18
Magnesia	0·00	0·00	0·00	0·00
Potash	0·00	0·00	0·00	0·00

1. Transparent rock salt from 660 feet.
2. Rock salt from the 14-foot bed.
3. Transparent rock salt from 650 feet.
4. Rock salt with anhydrite lenses from 645 feet.

Saline springs, depositing salt in naturally formed evaporating basins, occur in several places along the foot of an east-facing escarpment on the banks of Salt river west of Fort Smith. Camsell[1] reports the salt deposited in shallow basins about or near the brine springs issuing from the base of the escarpment. There is evidence that the salt probably did not come from bedded deposits but from crystals of the mineral disseminated through the gypsum beds in the base of the escarpment. The occurrence of bedded deposits of rock salt found by drilling near McMurray to the south and at Nintsi point to the north, however, suggests the possibility of bedded salt deposits at this point, at depth. Four groups of springs occur, the three important ones being: Snake Mountain springs, Hudson's Bay Company springs, and Roman Catholic Mission springs. Altogether about 4 tons of salt are annually collected from these springs for the trading posts and missions of the Mackenzie basin.

[1] Camsell, C., "Salt and Gypsum Deposits in the District between Peace and Slave Rivers, Northern Alberta," Geol. Surv., Can., Sum. Rep., 1916.

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No. 1. From Hudson's Bay springs, sample taken August 21, 1916
Contains in 1,000 parts by weight

Ions		Hypothetical combination	
Potassium	0·5	Potassium chloride	0·9
Sodium	101·5	Sodium chloride	258·0
Calcium	1·2	Calcium sulphate	4·1
Magnesium	0·2	Sodium sulphate	0·4
Chlorine	157·7	Magnesium chloride	0·8
SO_4	3·1		
	264·2		264·2

Temperature of air on collection	62° F.
Temperature of brine	42° F.
Sp. gr. at 65° F.	1·204
Flow about 1½ gals. per min. from each of eight springs.	

No. 2. Roman Catholic Mission springs, August 26, 1916
Contains in 1,000 parts by weight

Ions		Hypothetical combination	
Potassium	0·4	Potassium chloride	0·8
Sodium	100·8	Sodium chloride	256·3
Calcium	1·2	Calcium sulphate	4·2
Magnesium	0·2	Sodium sulphate	0·2
Chlorine	156·6	Magnesium chloride	0·8
SO_4	3·1		
	262·3		262·3

Temperature of air on collection	70° F.
Temperature of brine	35° F.
Sp. gr. at 65° F.	1·204
Flow about 3 gals. per min.	

No. 3. Snake Mountain springs, August 29, 1916
Contains in 1,000 parts by weight

Ions		Hypothetical combination	
Potassium	0·4	Potassium chloride	0·8
Sodium	100·7	Sodium chloride	256·0
Calcium	1·2	Calcium sulphate	4·2
Magnesium	0·2	Sodium sulphate	0·2
Chlorine	156·4	Magnesium chloride	0·8
SO_4	3·1		
	262·0		262·0

Temperature of air on collection	58° F.
Temperature of brine	40° F.
Sp. gr. at 65° F.	1·202
Flow in gals. per min.	4 to 5

These analyses show that sodium chloride constitutes in each sample over 97·6 per cent of the total solids. The percentage of 26 per cent dissolved matter indicates a saturated solution of salt at the brine temperature.

The Imperial Oil Company's oil well at Nintei point on Great Slave lake penetrated salt beds at 1,070 feet, 1,090 feet, 1,200 feet, and 1,380 feet, as shown by the log of the well previously given. All these salt beds occur in the Red beds underlying the gypsiferous dolomitic limestone of the Fitzgerald series. Samples obtained from the drilling operations on washing show a remarkably clear almost colourless rock salt carrying well over 90 per cent sodium chloride. Some samples are stained the characteristic brick red colour of the interbedded shales, whereas others are almost clear white. A total estimated thickness of 60 feet of salt is shown in the four beds mentioned above. The majority of the cuttings from the interbedded red shales show a considerable quantity of salt and gypsum intermixed with the shale.

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POTASH

Potassium salts are to be looked for in association with gypsum and salt beds and prospecting for them has been done near the gypsum beds on Peace and Slave rivers, but without success. The humidity of the region would not allow outcrops of the soluble chloride and sulphate salts to remain exposed. Until extensive drilling operations are carried on, the existence of potash deposits at depth can be determined only by analysis of underground waters that reach the surface.

The analyses already quoted of mineral-bearing waters show that the proportion of potassium is too low to be extracted on a commercial scale; and there is nothing to indicate that the water of these springs has passed through rocks containing an unusual proportion of potash.

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KENZIE RIVER DISTRICT BETWEEN GREAT SLAVE LAKE AND SIMPSON

By E. J. Whittaker[1]

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INTRODUCTION

The season of 1921 was spent in making a geological examination of the ıtry along Mackenzie river between Great Slave lake and Simpson (Map Micrometer surveys by canoe were carried up Horn river for 125 miles, rout river for nearly 100 miles, and up Kakisa (Beaver) river to and d lake Kakisa. This lake has a shoreline of over 60 miles and is much r than sketched on existing maps. Geological traverses back from the rs and lakes were made, the longest being into Horn mountains from a t on Horn river about 25 miles above Fawn lake.

The writer wishes to acknowledge the many acts of courtesy accorded him he various people whom he met. In particular he wishes to mention Mr.

[1] *Itinerary of Parties under E. J. Whittaker, G. S. Hume, and M. Y. Williams.* o the anticipated rush into the oil fields and the consequently uncertain nature of t conditions it was deemed advisable for the Geological Survey parties to be as dent as possible of outside aid. A scow was, therefore, built at Peace River, ta, in which the combined parties of thirteen men with the summer's equipment and es journeyed to their destinations. Two Evinrude motors gave steerageway to the ot scow and helped its progress downstream.

The journey was commenced on May 19. Aided by the swift current of the Peace rip of 350 miles to Vermilion chutes was made in five and a half days, during one of h the scow was tied up owing to heavy wind. After a short delay the scow with all o aboard was safely run through the rapids by a skilful pilot, Joe LaFleur of Fort ilion, and was lined, empty, over the lower chutes. The complete operation, includ- ortaging and reloading of the scow, occupied only half a day and by noon of May 27 ond stage of the journey to Fitzgerald began. This was accomplished without t and the parties reached Fitzgerald on May 31 almost exactly twelve days from ime of departure from Peace River.

The whole outfit was taken across the portage at Smith rapids by the tractor of the rta and Arctic Transportation Company, to avoid the risk of taking the scow through rapids.

At Fort Smith the Geological Survey parties joined forces with those of the Topohical Survey under Messrs. Seibert, Bowman, and Norrish, and all journeyed together r as Providence. Fort Smith was left at noon June 7 and the mouth of Sawmill nel, Slave river, was reached on the morning of the 10th. The worst weather of the was encountered on this stretch causing some delay. A fifth party, under Mr. chel, joined the flotilla a short distance above the mouth of the river, so that the plete parties now included about sixty men with five scows.

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Ballsillie, the Hudson's Bay Company's representative at Providence; the members of the mission at Providence; and Mr. Vale of Hay River. He wishes also to record the assistance and hearty co-operation of the Topographical Survey parties. Mr. A. K. McGill acted very capably as assistant.

GENERAL CHARACTER OF THE COUNTRY

MACKENZIE LOWLANDS

The area between the north arm of Great Slave lake and Mackenzie river is part of the Mackenzie lowlands. It is heavily drift-covered. This part in general is a flat plain with many lakes and muskegs and, except for very narrow strips along the banks of the rivers, is poorly drained. Although parts of the area are fairly well wooded there is a large amount of muskeg, either quite treeless, or else covered with sparse and stunted spruce trees. Belts of forest and treeless areas alternate irregularly. Almost the whole area drains towards the Mackenzie, except a narrow fringe on the west side of the north arm of Great Slave lake and south of lake la Martre. The drainage is effected by many small creeks and three rivers—the Horn, Spence, and Rabbitskin. All three are sluggish at their mouths, but soon contract and become swift and broken streams.

Horn river, which is much the most important, drains into Little lake near its upper end, but also connects by one large and many small intersecting channels with Mackenzie river. It averages 200 yards in width for the first 5 miles above its mouth and has a gentle current; then narrows to 200 feet and the current increases to 4 or 5 miles an hour. Its banks are low, seldom above 25 feet except for a short distance in the upper reaches where there are shale cliffs 60 feet high. With the exception of short stretches of lake-clays and the above-mentioned shale, the banks are composed of till from which came the many boulders that now occupy the bed of the river. Boulder pavements are common. Up to Fawn lake the country has been largely burnt over, and is now covered with a dense growth of young poplar as far back from the river as good drainage permits.

Mink, Birch, and Fawn lakes, also called First, Second, and Third lakes, occupy shallow depressions in the valley and have, except as hereafter noted, uniformly low willow-lined shores. The river is an almost continuous rapid except for the short distance between Birch and Fawn lakes. In that stretch it flows sluggishly in a wider, deep channel carved through lake clays, and it

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Great Slave lake had become free of ice about a month earlier than usual. A gasoline-power boat was chartered from Alex. Loutit of Resolution, and the journey was continued on the day of arrival. The scows were separately taken through the intricate channels off the delta of Slave river and assembled near Mission island where they were taken in tow at midnight by the motor boat. Favourable weather continuing, Hay river was reached on the afternoon of June 11 and after a short stay the last stage of the journey was undertaken and all the scows brought safely to Wrigley at the head of the Mackenzie, early Sunday morning June 12. The distance from Resolution to Wrigley by way of Hay river is nearly 110 miles. For many days and nights travel had been almost continuous and the day after arrival was devoted to rest and relaxation.

On June 13, at the upper end of Beaver lake, Mr. Blanchet commenced work on the survey of Mackenzie river. Providence was reached shortly after midday and here the Geological Survey party under Mr. Whittaker, and Mr. Seibert of the Topographical Survey, disembarked. Providence was the headquarters of Mr. Whittaker who, during the summer, examined the country between Great Slave lake and Simpson.

The other geological parties under Dr. Williams and Mr. Hume, continued together as far as Two-island Indian village, 31 miles below Simpson. The country between Simpson and Wrigley was geologically mapped, Dr. Williams working on the east side of the Mackenzie and Mr. Hume on the west. Although these parties acted independently, a common base of supplies was maintained on the scow which was moved slowly down the river for that purpose. By August 8 the work had been completed as far north as Wrigley and it was deemed advisable to visit the oil field at Norman. The journey was continued by scow as far as Norman, the outcrops along the banks of the Mackenzie being

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seems probable that these lakes were once united. The general course of Horn river from the Mackenzie to Birch lake is north 30 degrees east, but its course changes abruptly as it swings around the southeastern end of Horn mountains and as far as the survey was carried, continues north 50 degrees west. At this point the stream was 75 feet wide. Its principal tributary, Laferté creek, flows into Mink lake a short distance west of its outlet and drains the southern slopes of Horn mountains just as the main river above Fawn lake drains the northern, eastern slope.

Rising to a height of 2,000 feet from the monotonous plain of muskeg and lake, Horn Mountain range roughly parallels the Mackenzie and disappears opposite Simpson. These hills rise gradually to a height of about 1,200 feet above the plain in a distance of about 6 miles. At this height the slope is truncated by a level strip averaging 1½ miles wide, and then follows an abrupt rise of 400 to 500 feet to the top of the range, which is a plateau (Plate I A), almost treeless, covered with caribou moss, and dotted with small ponds. One of these ponds is worthy of being called a lake, being about 1½ miles long by ¾ mile wide.

Only the southeastern end of the range was explored. It averages 8 miles in width at this end, but apparently widens out farther to the northwest.

The trees on the bare plateau of the range show plainly the effect of the prevailing winds. The limbs all point to the southeast, and the northwest sides of the trees are scarred and limbless. Mink, Birch, and Fawn lakes have willowy and marshy shores on the northwest sides, but the southeast sides are covered with boulders and an occasional sand or gravel beach. This is evidently due to the prevailing winds, the heavy wave action on the southeast sides forming a beach in each case.

ALBERTA PLATEAU

The area lying to the south and west of Mackenzie and Liard rivers, excluding a narrow strip of low land along the Mackenzie from Great Slave lake to a point opposite Rabbitskin river, belongs to the physiographic province known as Alberta plateau. Its north and east boundaries are sharply defined by a prominent escarpment which extends from Hay river south of Great Slave lake, around the western end of the lake, and, after roughly paralleling the Mackenzie, disappears a short distance above Simpson. This escarpment can be first seen from the river just below Little lake. The plateau at the escarpment in this area averages 300 to 400 feet above the Mackenzie and gradually

studied at various places. The trip from Norman to the oil well of the Imperial Oil Company was made in a canoe fitted with an Evinrude motor, the return to Norman being made on August 16. While waiting there for the Hudson's Bay Company's steamer *Mackenzie River* the strata on Bear mountain and near Norman were examined. From the Tertiary beds a collection was made of plant material, a report on which by W. A. Bell accompanies the report of G. S. Hume.

The return trip commenced August 26. A very fast run was made without any delays and Edmonton was reached seventeen days later. At Providence Mr. Whittaker and party, who had returned only the day before from their last trip up Kakisa river, boarded the steamer, thus uniting the three geological parties after a separation of two and a half months. At Resolution Mr. Hume and one canoeman disembarked to visit Caribou island at the east end of Great Slave lake where the Aurous Gold Mining Company claim is located. The remainder of the parties continued up Slave river to Fort Smith which was reached on September 4. By the evening of the following day all the freight and passengers had been transported over the 16-mile portage. The trip up Slave and Athabaska rivers, on the steamer *McMurray*, was accomplished without delay and McMurray was reached Friday morning September 9. Passengers and freight were taken 18 miles up Clearwater river and across to the end of steel on The Alberta and Great Waterways railway in time to catch the weekly train reaching Edmonton Sunday evening September 11. Mr. Hume, who on his return from Caribou island, was not able to secure such prompt connexions, was delayed along with the Topographical Survey parties which did not leave Fitzgerald until September 25. The same route was followed and Edmonton was reached on October 2.

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but slowly rises to the eastern range of Rocky mountains. The drainage is poor and the country is covered with muskegs and lakes, though not so much so as the Mackenzie lowlands. Between Great Slave lake and Simpson the area is drained by Kakisa, Bouvier,[1] Redknife, Trout, and Liard rivers. These rivers are all very much alike. They are turbulent, broken, and swift in their upper reaches and pass over the escarpment to the lowlands by a series of falls and rapids, where the river has cut down to the underlying rock. Elsewhere a heavy mantle of drift has prevented the streams from cutting down to bedrock.

Trout river is nearly half a mile wide at its mouth, but rapidly contracts to 150 feet and flows between gravel bars in a low valley about 2,000 feet wide cut in the boulder clay. Upstream the river becomes swifter and narrower and is broken by rapids much greater than those on Horn or Hay rivers. Seventeen miles above the mouth the valley contracts and the river flows at the bottom of a deep gorge with perpendicular cliffs rising 125 feet. The current runs in this gorge from 6 to 8 miles per hour, but is so smooth that it is only when seen foaming around some obstruction that a proper conception can be formed of its speed. Three miles above the lower end of the gorge are two heavy unnavigable rapids. Just above this point the river makes an S bend and in quick succession passes over three falls, a cascade of 10 feet, a fall of 47 feet passed by a portage one-third mile long, and, half a mile above the latter, another fall of 17 feet passed by a portage of a few yards.

Above the falls the river, which has pursued a generally southerly course since leaving the Mackenzie, turns to about 20 degrees south of west, and maintains this course as far as the survey was carried. The valley widens to over a third of a mile, with vertical cliffs on the outer sides of the bends. The current is easier, and, eighteen miles above the falls, the river leaves the cut banks behind and flows through a flat plain which averages only 6 feet above the river. One low dome of limestone projects 20 feet above this plain for a distance of three-quarters of a mile. The river in this section widens to 200 feet with long straight reaches in which the channel is studded with alluvial islands. Here were discovered the first traces of Indian habitation since leaving the Mackenzie, for the natives avoid the lower river. The current averages 4 miles per hour. Forty miles above the falls this low, level plain which represents the bed of an old lake gives way to higher land underlain by boulder clay, which continues as far as the survey was carried. Through this country the long, straight stretches of river are replaced by short bends carved in the boulder clay, and the river is an almost continuous boulder rapid. Trout lake was not reached before shallow water compelled abandonment of the survey. At this point the country is about 1,000 feet above the Mackenzie. Trout lake is apparently a little west of its sketched position on the maps. In the last 30 miles surveyed the river drops 350 feet and its current averages 7 miles an hour. In its entire course Trout river receives only three very small tributaries, each about 12 feet wide, and so retains its volume of water throughout. It cannot be considered in any sense a navigable stream.

The falls are produced in the same manner in each case. A hard, resistant bed of limestone forms the top of the falls and is underlain by softer, shaly limestones or sandstones, which wear back more rapidly than the limestones.

Redknife river was not explored, but from an examination just above its mouth it seems to be less than half the size of the Trout and probably is less than 100 miles long.

[1] The name Bouvier has been applied to this river by G. H. Blanchet of the Topographical Survey Branch, Dept. of the Interior. It refers to M. Bouvier, a pioneer of this country, now living at Providence.

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Bouvier river, which is nearly equal in volume to Redknife river, flows in from the south side about 25 miles below Little lake. It discharges muddy water instead of the brown water characteristic of these streams.

There are no streams of importance on the south side of the Mackenzie between Bouvier river and Kakisa river.

Kakisa river heads in the highlands of the Cretaceous plateau to the southwest and pursues a general northeasterly direction to join the Mackenzie 30 miles above Providence. It averages 200 feet in width. In its course it flows through two large lakes, Tathlina and Kakisa. It enters the Mackenzie by two main and several small channels. About 2 miles above its mouth the river is dotted with islands and very much resembles a former delta, when the Mackenzie stood at a higher level than now. This river is cutting down its bed very slowly, for cut banks are rare. Even in the short gorge below Lady Evelyn falls—9 miles above its mouth—the river bank is forest-covered, and, owing to overhanging bush, is bad for tracking. The river cascades at intervals over ledges of limestone along a 4-mile stretch in the middle of which is Lady Evelyn falls. These are passed by a lift-over at the lower cascade, 6 feet high, a portage of ¾ of a mile past the big falls and cascades, and a short portage of 200 yards past the upper cascade, 4 feet high. Lady Evelyn falls is a beautiful vertical cataract 47 feet high. From the upper cascade the river is smooth but swift to lake Kakisa.

Lake Kakisa is nearly 25 miles long, and its long axis lies 25 degrees north. It is about 8 miles wide at its eastern end and gradually narrows to less than 3 miles at its western end. It is quite shallow, seldom being over 12 feet deep. Its shores present abrupt contrasts in topography. The northern shore is low and uniform, seldom rising more than 6 feet above the water and, back of that, the country is largely muskeg. The southern shore is more rugged, showing large boulder beaches and wave-cut rock cliffs, and back from the shore 200 feet above the lake is an abrupt escarpment, apparently the one seen farther down the Mackenzie. It continues southeast of Kakisa river as a broken line of grass-covered hills which reach Eagle mountains. South of this escarpment the country is flat and the rock lies close to the surface. This has been deeply cut by many small streams and by Kakisa river between lakes Tathlina and Kakisa. The western end of lake Kakisa is very marshy. The north side has the typical muskeg drainage of many small streams 2 or 3 feet wide. On the southern side are four small streams, apart from Kakisa river. This river becomes swift and broken about 2 miles above its mouth and remains so to lake Tathlina, two portages being necessary to pass the worst chutes. According to Mr. Seibert of the Topographical Survey the river is swifter than below lake Kakisa, but tracking is easier. The first portage is on the west bank of the river and is three-quarters of a mile long. Above this, for about a mile, the river passes through a shallow gorge flanked by ledges of limestone 15 to 20 feet high. By taking advantage of slack water, first on the west and then on the east side, a canoe may be paddled through this stretch of the river, except for a chute at its upper end necessitating a short portage. For 5 miles above this point the stream widens out, the banks become lower, and the current is easier. Above this wider part and up to lake Tathlina the river narrows between high limestone banks and flows at 8 miles an hour in a series of rapids. Tracking is good at ordinary stages of water.

Lake Tathlina is much larger than indicated on existing maps. Thirty miles of the north shore was traversed by Mr. Seibert and the eastern end of the lake was not visible. It is very shallow and its shores are low and swampy. Kakisa river flows in at its western end. It is much reduced in size and navigable for canoes for about 15 miles only. South of the lake, the land rises

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rapidly for several hundred feet to form what are known locally as the Cutknife hills. A deep valley is cut in these hills by a large river which enters the lake 12 miles east of its western end.

South of Cutknife hills the land continues to rise slowly and at the junction of the sixth meridian and the Alberta-Northwest Territories boundary (latitude 60 degrees, longitude 118 degrees) its elevation is about 2,500 feet above sea-level. The same monotonous succession of muskeg and pond characterizes the country here as elsewhere. From the above position lake Batcho can be plainly seen away to the southwest.

Mackenzie river has been so fully described elsewhere that the writer need only state that from Great Slave lake to 10 miles above Providence the banks are low and unimpressive. From this point to Little lake (also called Mills lake) the river is narrower and swifter, and passes through a boulder-clay area. From the above lake to the Head-of-the-Line, the river is once more broad with gentle current and low banks. From this point to Simpson it is narrow and swift, and has carved its bed deeply into the boulder clay.

TIMBER

The timber of this area is not of a very high quality, the majority being suitable only for pulpwood and the stand per square mile averages low. Spruce and birch of good size are found on the lower, well-drained slopes of Horn mountains, but are not easily accessible. Elsewhere the forest has been largely reduced by fire. Birch suitable for canoes is obtained at a few favoured localities only. All the Indians at Providence obtain their birch bark from Birch lake on the route from that fort to Rae. Tamarack is very common along the lower ground, but no large living trees were observed.

FISH AND GAME

The area cannot be said to be a good big-game country. During the whole summer only three moose, one bear, one fox, and one beaver were observed by the party. In the rivers jackfish or pike are abundant. Bluefish are found in Trout river above the falls, and at the head of several islands opposite Providence. The inconnu and whitefish are found in Little lake, more rarely at Providence, and abundantly at Wrigley. Whitefish of large size occur also in lakes Kakisa and Tathlina. The lake trout is found rarely below Little lake. Suckers are everywhere abundant in the river eddies. In the muddy water of Liard river fish are very scarce.

The area about Little lake and the lakes on Horn river and in Horn mountains teem with ducks and geese, and geese are very common up Trout river, 20 miles above the falls, and also on lakes Kakisa and Tathlina. The snow-goose or wavy is less common. Waterfowl are abundant along the Mackenzie between Great Slave lake and Kakisa river, but as this section is well-travelled they are shy. Spruce partridge are abundant in the wooded slopes of Horn mountains. In the winter the Indians shoot and trap the common fur animals, but the returns are poor compared, for instance, with parts of northern Ontario.

TABLE OF DISTANCES ALONG RIVERS

Kakisa River

	Miles
From outlet to Lady Evelyn falls	9
" " " outlet of lake Kakisa	14
" " " point where upper Kakisa river enters lake Kakisa	25
" " " lake Tathlina approximately	45[1]

[1] Information on the upper Kakisa river kindly supplied by Mr. F. H. Seibert of the Topographical Survey Branch, Dept. of the Interior.

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Horn River

From outlet	to outlet Mink lakes	36
" " "	" Birch lakes	56
" " "	" Fawn lakes	65
" "	" Sulphur creek	78
" "	" Horseshoe rapid	94
" "	" end of micrometer survey	123

Trout River

From outlet	to Table Rock rapid	14
" "	" Second falls	20
" "	" Big Bend	22
" "	" foot of upper rapids	64
" "	" end of micrometer survey	97

NATIVE INHABITANTS

The Indians in the area under discussion belong, with one exception, to the Slavi tribe. They are divided into several distinct bands. One band which hunts and traps up Horn river and in Horn mountains is referred to as the Horn River Indians. They come to Providence to trade in the spring and remain near the mouth of Horn river, supporting themselves by fishing until the autumn when they return up the river to their hunting grounds. On the headwaters of Horn river a band of Dog-Rib Indians, who come in from Rae, encroach upon their hunting grounds. This is common knowledge and is corroborated by the fact that the writer discovered in this locality a starving dog, which followed the party to the mouth of Horn river and was not claimed or recognized by any of the Horn River band, all of whom were assembled at this point at that time. Hence it seems probable that it belonged to the Indians from Rae.

Another band of Indians, known as the Trout Lake band, live on the shores of Trout lake. They do not descend Trout river to its mouth, but travel overland to Liard river to trade at either Simpson or Liard.

A third band lives at the west end of lake Tathlina and trades at Providence. This band seems to have had a composite ancestry which embraces Trout Lake Indians, Indians from Hay river and Providence. Confusion has arisen because this band also is referred to as the Trout Lake Indians. In general these Indians have kept themselves aloof from the Indians and white men along the Mackenzie, and are a superior type. They have the reputation of being more industrious, skilful in hunting, and reliable than other Indians of the district.

GENERAL GEOLOGY

In the area under discussion formations of Devonian, Cretaceous, and Pleistocene age are recognized. The general section is as follows:

Table of Formations

—	—	Thickness
		Feet
Pleistocene and Recent	Boulder clay, alluvial and lacustrine deposits	20–100
Cretaceous	Mountain shales	100–500
Upper Devonian	Hay River beds	700
	Simpson shales	150
Middle Devonian	Pine Point limestones	100
	Horn River shales	100

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HORN RIVER SHALES

The shales to which the name Horn River is here applied are first seen on Horn river 11 miles above Fawn lake. They outcrop at frequent intervals along the river, at least as far as the survey was carried. They are brown-black, fissile, much jointed and fractured. One set of joint planes runs about east 10 degrees north, but others, less conspicuous, run about due north and south. These shales are either quite horizontal or dip very gently toward the southwest. Locally, small folds with maximum dip of about 3 degrees are observed. No fossils were observed, though minute markings at first thought to be *Styliolinas* were noted. Sixty feet of these shales were seen with the lower part covered. Owing to their position immediately below the Pine Point limestones, they are placed in the Middle Devonian.

These shales may be identical with the upper part of the red and reddish brown shales reported from the Nintsi Point well at a depth of 1,040 feet.

PINE POINT LIMESTONES

This formation was encountered at only two localities, both up Horn river about 30 miles above Fawn lake. Fifteen feet of flat-lying limestone were observed immediately above the Horn River shales. The upper surface has been smoothed and gouged by glacial action. These limestones are dark grey and certain layers are quite fossiliferous. The fauna is similar to that seen at Resolution, being characterized by a large flared *Atrypa, Paracyclas, Martinia,* cf. *meristoides,* and a small *Schizophoria.* The nearest exposure of this formation previously observed is on the north shore of Great Slave lake just west of Hardisty island, 120 miles distant.

On the east side of the Mackenzie no rocks were found between these beds and the Cretaceous. All the Upper Devonian is covered. The lowest beds of the Cretaceous exposed are about 15 miles away and 1,200 feet above the Pine Point limestones.

SIMPSON SHALES

These shales are exposed on Mackenzie river 5 miles above Rabbitskin river in the first rock exposure on the river below Great Slave lake. They are also exposed at intervals down to Simpson and up Liard river for 20 miles. The fauna is very characteristic, but extremely restricted. The characteristic species are *Buchiola retriostriata* and *Entomis brookei.* This formation probably underlies a part of the low land bordering the Mackenzie.

HAY RIVER BEDS

A nearly complete section of limestones and shales of the Upper Devonian corresponding to the Hay River limestones is exposed along Trout river and to a lesser extent along Kakisa river and to the south of lake Kakisa. The section exposed along Trout river is as follows:

(*Top*)

	Feet
t. Rubbly-weathering, grey limestone, fossiliferous with *Leiorhynchus* sp. common	4
s. Thin-bedded, grey to buff limestone, rarely fossiliferous, with *Leiorhynchus* and *Productella*	4½
r. Decomposed shale band, unfossiliferous	½
q. Heavy-bedded, grey, rubbly limestone. Beds 2 feet thick, fossils common including *Leiorhynchus, Camarotoechia, Euomphalus, Bellerophon* cf. *macra*	16
Covered interval about	40
p. Pure, fine-grained, grey limestone. Fauna as above, but including also *Schizophoria.* Conspicuous joint planes east 20 degrees north	10

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HAY RIVER BEDS—*Continued*

(*Top*)—Continued

o. Fine-grained, buff weathering limestones. Cavities filled with pitch. Characteristic fossil *Athyris* cf. *angelica* ..	15
NOTE.—Above beds are exposed as low ramparts for a long distance along the river.	
n. Grey, impure, sandy limestones averaging 20 inches thick, interbedded with grey green sandstones and sandy shales. Characteristic fossil *Spirifer whitneyi*..	88
m. Porous, buff, dolomitic limestone with poorly preserved corals.	4
Top of Third falls	
l. Heavy-bedded, pure, fine-grained limestones, very irregular in thickness, abundant fauna including *Cryptonella* cf. *pinonensis, Diaphorostoma* and other gastropods, *Fenestella, Gypidula*..	14
k. Soft, greenish, impure limestone with shaly partings, with an abundant coral fauna and crinoids..	6
j. Limestone coral reef..	12
i. Thin-bedded, grey limestone with poorly preserved corals..	21½
Top of Second falls	
h. Irregularly-bedded coral reef with some large corals 4 feet in diameter..	6
g. Grey, sandy limestone with poorly preserved corals	8
f. Heavy-bedded coral reef. Conspicuous horizon, full of nodules of marcasite which weather rusty..	3
e. Grey, thin-bedded, shaly limestone with shale partings	30
Bottom of Second falls	
e. Same as above..	17
Top of First cascade	
d. Thin-bedded limestone with abundant fauna including *Spirifer disjunctus* and many corals..	36
Covered interval measured by aneroid..	45
c. Soft, blue-grey shales with thin bands of sandy limestone. Fossils include *Atrypa spinosa* and a large *Chonetes*..	30½
b. Compact, pure, grey, limestone weathering buff, with an abundant molluscan fauna, *Hypothyris cuboides* and a form resembling *Spirifer disjunctus* var. *occidentalis*..	8
a. Limestone as above, but with a large coral fauna including *Acervularia* and *Phillipsastræa; Spirifer disjunctus* and *Schizophoria striatula*..	35
Total thickness of section..	454

NOTE. The base of Zone *a*, the lowest beds seen on Trout river, is, according to aneroid, 90 feet above the level of Mackenzie river.

The above section lies entirely within the limits of the formation called by Cameron the Hay River limestones, but includes higher beds than those exposed on Hay river. The most restricted and conspicuous horizon, and the one most useful for correlation, is Zone *l*, which outcrops along the edge of the escarpment for a long distance. There is a submarine unconformity at the top of this zone. Zones *o* to *t* are characterized by an abundance of *Leiorhynchus* and may be referred to as the *Leiorhynchus* zone. Zones *m* and *n* may be called the *Spirifer whitneyi* zone, as they are characterized by that fossil. Zone *l* may be called the *Cryptonella* zone (Plate II A, B). Below this horizon the section is characterized by the widely disseminated form *Spirifer disjunctus* and is called by that name. Lithologically, however, the *Leiorhynchus* and the *Cryptonella* zones are the only ones readily distinguished.

The section on Kakisa river is similar, but not so thick. The *Cryptonella* zone, which here forms the top of the section, to the south of lake Kakisa is notable for the extreme abundance of *Hypothyris cuboides*, a form rare else-

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where. It also contains a new trilobite, and *Conocardium* in abundance. At Lady Evelyn falls the river drops over strata of the *Spirifer disjunctus* zone, but much lower down in the section than the beds at the falls on Trout river. The rocks exposed at the top of Lady Evelyn falls correspond to the lowest beds seen on Trout river, and 60 feet of strata in the section at Lady Evelyn falls are, consequently, not seen in the Trout River section. Although part of the section between the falls and the escarpment is covered, the upper and lower limits are well exposed.

The Liard River section at the rapids 30 miles above Simpson cannot be correlated so readily in detail with the Trout River section. About 150 feet of sandstones and sandy limestones undoubtedly belong to the *Spirifer disjunctus* zone. These are underlain by about 60 feet of dark grey shales with an occasional bed of limestone which probably belongs to the same zone, but may correspond to lower beds not seen on Trout or Kakisa rivers.

CRETACEOUS

The Mountain shales are exposed near the top of Horn mountain along many of the small streams (Plate I B) which drain the plateau and slopes. The very heavy deposit of drift including large boulders has acted as an effective check on the cutting down of their valleys. The upper 400 feet is entirely drift-covered, and not a single exposure of rock was found in any of the traverses. From the topography it might be concluded that a heavy bed of sandstone capped the formation, but not even a fresh boulder was found to substantiate such a supposition. The shales outcrop at the top of the wooded gentle slope which rises from the muskeg plain, 80 feet in all being exposed. They are thin, fissile, and brown-black and weather yellow.

Throughout these shales, bands, 1 to 2 inches thick, of a decomposed hydrous aluminum silicate, occur. The silicate is white except where stained by iron, and has the plastic consistency of brick clay. For 6 inches above and below these beds the shales also are much decomposed and jet black. More rarely and near the top of the section are bands, averaging 2 inches thick, of ironstone, many developing incipient concretionary structures. Yellow ochre from the decomposition of these ironstones is found in considerable quantities along the upper reaches of the creeks. Another decomposition product is sulphur, of which small quantities were observed coating crevices in the shales. Combustion of this sulphur accounts probably for many small irregular patches in the shales which are reddened and hard and seem to have been baked.

Fossil collecting produced nothing but some unrecognizable plants and some fish remains, no invertebrate remains being discovered. The collection has not yet been critically studied, but there appears to be no doubt the remains are Post Palæozoic and similar to undoubtedly Cretaceous remains discovered near Norman by Kindle in 1919.

But little structure was observed. The beds are horizontal, though local folds are occasionally formed by great masses slumping down into the ravines.

On Trout river, 67 miles above its mouth, for about 100 yards along the north bank of the stream, similar shales are exposed. They are more decomposed than those exposed on Horn mountains and fossils are very rare. The shales are impregnated by minute crystals of gypsum. Beds of ironstone and of white, hydrous, decomposed, clay material occur as in the Mountain shales. Many septarian concretions occur at the base of the section. Twenty feet only are exposed and its base is about 150 feet above the highest Palæozoic beds observed.

It is probable that the high land observed by Mr. Seibert south of lake Tathlina is also underlain by Cretaceous strata.

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PLEISTOCENE—RECENT

A heavy mantle of boulder clay covers nearly the whole area, and—especially east of the Mackenzie—has prevented the streams from cutting down to the underlying rock. It is well exposed along the Mackenzie from above Providence to Little lake and from the Head-of-the-Line to Simpson, as well as along the subsidiary streams. The irregularities in its surface are occupied by shallow lakes and ponds. From one point in Horn mountains over sixty of these were observed, of which those on Horn river were among the largest. Glacial striæ were observed at one point only—on Trout river 18 miles above the Third falls. Two sets were observed running south 67 degrees west and south 50 degrees east. It was impossible to determine definitely their relative ages, but those running south 50 degrees east appeared to be the older. Lacustrine deposits of clay, and more rarely sand and alluvial sediments of clay, sand, and gravel, complete the recent deposits. A considerable deltal island has formed at the mouth of Horn river where it enters Fawn and Mink lakes. In passing through the very short distance between Fawn and Birch lakes, the river, not having much opportunity to erode its banks, does not carry any such burden of sediment, and hence no delta is formed.

OIL POSSIBILITIES

As noted above, very little structure is to be observed. The formations exposed along Horn river, even if the structure were suitable, are too low down in the section for any large oil accumulations to occur. Twelve hundred feet of strata lie between the highest Pine Point limestone and the lowest Cretaceous, but the bottom of the Cretaceous was not observed and it is impossible to calculate the thickness of Devonian sediments, though they probably thin out considerably to the east. With the known sediments above and below lying horizontal, it is improbable that there is any anticlinal structure in the potential oil-bearing formations.

Above the falls on Trout river, there is a low dome in the limestone, which, however, soon becomes horizontal again. This is the most prominent of several very gentle folds, whose dips are not over 2 or 3 degrees. Geological conditions are more favourable here for oil accumulation than elsewhere, though there is no evidence that the structure extends to the oil-bearing strata. As in the above case, however, the locality is not yet commercially accessible.

MINERAL SPRINGS

On Sulphur creek, a small tributary of Horn river, are several small sulphur springs, one of which is accompanied by a considerable flow of hydrogen sulphide. These springs apparently originate in the Horn River shales.

The waters of all the streams heading in the Cretaceous shales in Horn mountains are heavily impregnated with iron, which, however, is deposited before the plain is reached.

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EXPLORATION EAST OF MACKENZIE RIVER BETWEEN SIMPSON AND WRIGLEY

By M. Y. Williams

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INTRODUCTION

The work undertaken by the writer during the field season of 1921 was an exploration of the country bordering Mackenzie river on the east, between Simpson, at the mouth of Liard river, and Wrigley. Towards the close of the season, a trip was made with G. S. Hume to the discovery well of the Imperial Oil Company, Ltd., 56 miles below Norman.

The writer was ably assisted by A. H. Bell. Valuable aid was rendered by officers of the Hudson's Bay, Northern Trading, and Alberta and Arctic Transportation Companies. The local information obtained from Mr. Fred Camsell, factor at Simpson, was especially useful and made it possible to carry on explorations back from the river with expedition and success. Hearty co-operation existed with the government officials, viz., the officers of the administrative parties, of the topographical and hydrographical surveys, and of the astronomic party. Officials of the Imperial Oil Companies were most kind and assisted the work in every way possible.

WORK ACCOMPLISHED

Work was started at Simpson on June 16. The shale outcrops opposite the Post were examined and from there downstream the right bank was followed, and it is believed no outcrops were overlooked. From Two-island Indian village, 31 miles below Simpson, an inland traverse was made over an Indian winter trail. This survey was run by pace and compass, the only feasible method where timber is prevalent. It was accomplished in ten days, a return being made to the scow or base of supplies by June 27. On June 30 the exploration of Willow Lake river was begun. The survey of this river with compass and Rochon micrometer for nearly 70 miles occupied about two weeks, after which a study was made of the south end of Franklin mountains. This was followed by another overland trip through the bush to the mountains, starting from just south of the point known on Ogilvie's map as the River-between-two-Mountains, where the mountains are about 6 miles distant from the Mackenzie.

After carefully examining the rocky island at the site of old Fort Wrigley, two traverses were made from near Smith creek,[1] on one of which a point

[1] Eleven miles above Wrigley.

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in the Franklin range 8 miles distant from the Mackenzie was reached. On July 29 camp was moved to the east bank of the Mackenzie about 1 mile above Wrigley and the rocky island just above the Post and Roche-qui-trempe-à-l'Eau were studied. Eight days were occupied by a trip over an Indian winter trail to Cap mountain which lies about 14 miles east of Wrigley.

The remainder of the season's work was done in conjunction with G. S. Hume in an examination of the outcrops along the Mackenzie as far north as Norman; and on a visit to the Imperial Oil Company's well. While waiting for the steamer *Mackenzie River* at Norman, a study of Bear mountain was undertaken and the Tertiary in the vicinity was also examined.

GENERAL CHARACTER OF THE REGION

PHYSIOGRAPHY

The region between Simpson and Wrigley consists of the following physiographic subdivisions:

The Mackenzie River lowland which is adjacent to the river; the Mackenzie and Franklin mountains farther back from the river; and groups of hills—remnants of an older plateau—south of these mountains.

The present topography is a modification of a land surface that dates back to pre-Tertiary time, for undisturbed Eocene beds occupy a considerable part of the valley above Norman. In fact the highlands suffered erosion in Cretaceous time, the Cretaceous sediments being mainly clastics derived from the Devonian rocks.[1] That little earth movement has taken place since Cretaceous time is indicated by the gentle folding of the Cretaceous sediments, which contrasts strongly with more intense folding of the underlying Devonian strata.

Mackenzie Lowland

The Mackenzie lowland is mainly excavated in soft shales and sandstones of Upper Devonian age, but here and there a mountain spur or anticline of Middle Devonian limestone has been cut through. Side streams draining lakes to the eastward flow through Franklin mountains in narrow gorges suggestive of ancestral streams of greater importance. The extent of the lowlands is in fact suggestive of the valley of an ancestral river, which had reached a stage of advanced maturity. The lowland is now occupied by strata of Cretaceous, Eocene, and Pleistocene age, Mackenzie river flowing for the most part through the younger unconsolidated silts, sands, and gravels. Many lakes and ponds scattered over the floor of the lowland in the vicinity of the river, and terraces occurring commonly at different heights above the present river level, indicate that the river has meandered to a considerable extent since glacial time. The present incised channel has resulted probably from down-cutting at the ramparts, and consequent increase in grade.

Between Simpson and the mouth of North Nahanni river, the lowland is bordered by hills which are remnants of an older land surface. Ebbutt hills[2] are situated about 10 miles from the river at Two-island village, and rise about 1,500 feet above the river level. The underlying rock is soft Upper Devonian shale. The hilltops are plateau-like, and are covered with muskeg, black spruce, etc., as on the lowland. The side facing the river is steep, with escarpments at some places, and is being rapidly eroded by brooks that descend by steep and narrow channels. From the hills the land surface slopes more and

[1] Kindle, E. M., and Bosworth, T. O., Geol. Surv., Can., Sum. Rept., 1920, pt. B, p. 53.
[2] Named after E. Ebbutt of the writer's party.

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more gently toward the river. It is covered by muskeg, and tundra, with here and there a meandering stream or small river finding its way across the glacial deposits, and around local sandhills.

At the mouth of North Nahanni river, the Mackenzie lowland is deflected northward by Mackenzie mountains, and north of the mouth of Willow Lake river is shut in on the east by Franklin mountains.

Franklin Mountains

The southern part of Franklin mountains included in the area extending north of Willow Lake river to near Wrigley consists of sharp, but open, southerly plunging folds, the axes of which control the trend of the river. Just north of Willow Lake river, two ranges, about 10 miles apart, appear to represent the east and west limbs of an eroded anticline, although it has not been established that there are no intervening folds. The easterly ranges die out 4 or 5 miles north of the latitude of Fish Lake river, the westerly range where traversed by this river containing an open anticlinal axis, with its eastern limb truncated. Farther north, due to the rising axis, older formations are exposed and the mountains are high and more complex, and cover a broader belt.

At Smith creek the western range has split into two, the eastern branch being subdivided into several irregular ridges, extending in different directions. Opposite Wrigley, the Roche-qui-trempe-à-l'Eau forms the westernmost ridge of the Franklin system. Four miles to the east the mountains rise as a somewhat dissected mass, which may be grouped into two main ranges, with another which there forms the easternmost part of the system, dying out to the north. The folded nature of the mountains is quite apparent, and shows especially well in the two eastern ranges, between which there is probably a strike fault. The lowland to the east is covered by almost innumerable lakes which drain westward to Mackenzie river. Farther east, however, is a low divide, beyond which large lakes of La Martre system could be faintly discerned. Cap mountain,[1] which in its southern extent is flanked by a ridge to the east, consists of a quartzite ridge dipping steeply to the west and rising in elevation at its northern end where it forms the highest mountain of the Wrigley region—its height being estimated at more than 5,000 feet above sea-level. As will be shown elsewhere, the eastern side of the mountain is probably a fault scarp. The limestone mountain resting upon its flank to the west has been named mount Kindle by the writer, in honour of the first geologist to visit this locality, and the highest mountain on the south side of Fish Lake river has been named mount Bell after A. H. Bell of the writer's party.

[1] This mountain was named by Kindle in the report cited above.

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GENERAL GEOLOGY

Table of Formations

Quaternary	Recent		River silts, marls, and peat
	Glacial		Tillites, outwash gravels, sands, and clays
Paleozoic	Devonian	Upper	Simpson shale and overlying limestone
		Middle	Grey limestone veined with calcite, and some selenite, and containing numerous remains of gastropods, bivalves, and corals
	Silurian	Upper	Cavernous dolomite.
		Middle (Mount Kindle formation)	Halysites and other corals
		Lower (Franklin Mountain formation)	Red and green shales, in part sandy
	Ordovician?		Soft red and green shales
	Cambrian	Upper? (Mount Cap formation)	Sandy shales and thin-bedded sandstone above, and below thick-bedded, pink quartzite

CAMBRIAN: MOUNT CAP FORMATION

The oldest rock seen in the area occurs on Cap mountain, about 14 miles rthwest of Wrigley. Here a westerly-dipping, truncated fold of heavy-bedded uartzite forms the elevated ridge called Cap mountain. At the top of ed section are 100 feet or more of grey and rusty shales or phyllites, rlying green and rusty, thin-bedded sandstones, which rest upon pink artzite. The section of the sandstone and quartzite farther north is described Kindle[1] thus:

	Feet
Red quartzite and sandstone (summit of mountain) dip 10 to 15 degrees west	500 plus
Red shale and ferruginous sandstone	50
Hematite	20
Red sandstone with high percentage of iron	50
Dark shales	150
Greyish to drab shale	225

mation dips southwesterly at 10 to 15 degrees and passes under a ain which carries at its summit Middle Silurian corals (*See* cross-ction on Map 1957), as described below. There is also direct evidence of the e of the Mount Cap formation in the presence of free cheeks of a trilobite obably of genus *Saratogia* in the thin sandstones near the top of the section. his genus occurs in the Middle, but more commonly in the Upper, Cambrian. n such generic characters establish the Cambrian age of the beds and point rongly to late Cambrian time. As will be seen, this conclusion does not ree with the tentative age described by Kindle. Dr. C. D. Walcott, to whom ese specimens were referred, writes concerning them as follows: "The sur-ce of the piece of quartzitic sandstone might have come from most any of e arenaceous shales of the Upper Cambrian formations of Montana and daho. There is very clear evidence of the presence of a Cambrian form of rilobite closely related to species that have been referred to *Saratogia*. There s also one impression that strongly suggests *Agnostus*, but it is too doubtful o mention it."

[1] Sum. Rept., 1919, pt. C, p. 2 C.

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The limestone and underlying shales in knobs and ridges to the east, dip away from Cap mountain and are so close to the escarpment as to preclude the possibility that the quartzite may change its direction of dip and pass below them as the east limb of an anticline. Evidence points to the presence of a fault as indicated on the map and cross-section.

The base of Mount Cap formation[1] was not seen, nor was the top determined; it is probable, however, from the observed outcrops and structure that the thickness is between 1,000 and 1,500 feet.

SHALES OF PROBABLE ORDOVICIAN AGE

A cover of loose deposits obscures the bedrock to the west of Cap Mountain ridge (where examined by the writer) as far as the base of mount Kindle. The under phyllites of Mount Cap formation probably underlie a part of the intervening 4,000 feet, but soft red clay shale outcrops at the base of mount Kindle as though squeezed out by the overlying mass of rock. Although little is known of this formation, it lies between the Cambrian and Silurian formations, and is thought to be of Ordovician age.

SILURIAN FORMATIONS

On the eastern declivity of mount Kindle, pea-green shales and red, sandy shales litter the talus for hundreds of feet, and rocks are found in place between 420 and 480 feet below the outcrop of the Middle Silurian coral horizon. No fossils were found in these shales nor were the limits of the formation seen, but from stratigraphical position, and because of the general similarity to lower clastic Silurian sediments known elsewhere, this formation is provisionally classed as Lower Silurian, the name Franklin Mountain formation being applied to it from its occurrence in Franklin mountains. It is thought to be not less than 500 feet thick. Sections of the formation outcrop in the face of the mountain to the south of mount Kindle and also in the mountain to the east of the southern end of Cap Mountain ridge.

The upper 80 feet of mount Kindle and its western slope for a mile or more consist of grey magnesian limestone, composed in large measure of the fossilized remains of Silurian coral reefs. As will be seen from the following determinations, these corals are characteristic of Middle Silurian time, especially as represented by the life of Niagaran seas of eastern and central North America. The writer proposes to name this the Mount Kindle formation because of its splendid development on this mountain, near which Kindle first obtained specimens of the contained fauna. Judging from outcrops and structure the Mount Kindle formation may be 500 feet thick.

The following fossils have been recognized. In the creek to the south of mount Kindle: Cyathophylloid coral, probably new genus and new species, *Columnaria alveolata* Goldfuss?, *Diphyphyllum multicaule* (Hall), *Halysites catenularia microporus* (Whitfield), *Bumastis ioxus* (Hall)?.

At the top of mount Kindle: Stromatoporoids, *Zaphrentis stokesi* Edwards and Haime, *Diphyphyllum multicaule* (Hall), *Cladopora multipora* Hall, *Halysites catenularia microporus* (Whitfield).

About 100 feet higher in the section, but down the west slope of the mountain: *Zaphrentis stokesii* Edwards and Haime, and *Conchidium* sp. in a boulder probably not far out of place.

[1] The name "Cap mountain" is preferable, but is pre-empted, being used for a Cambrian formation in Texas.

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The Mount Kindle formation appears to grade upward into rough cavernous dolomite which is much cut by calcite veins. Somewhat similar rock was seen on the crest of the anticline at the top of Roche-qui-trempe-à-l'Eau, and elsewhere at crests of anticlines in the Franklin range. The upper "brecciated" dolomite of Kindle's Bear Mountain formation is similar in many ways to this cavernous formation, but as metamorphism has had a marked effect on the limestones and dolomites of the Franklin mountains, it seems unwise to attempt to correlate formations of widely separated areas except on the basis of fossils, or impressive stratigraphic evidence. The cavernous dolomite is, probably, 500 feet thick. The exposures in the mountains in the vicinity of mount Kindle will probably make it possible, however, to work out a complete Silurian section. Until this be done, it will be uncertain whether the red clay shales and gypsum of the Bear Mountain formation are represented in the Mount Kindle region.

MIDDLE DEVONIAN LIMESTONES

The common limestones of the Franklin Mountain region are Middle Devonian in age according to their fossil content. From the southern tip of the range, near Willow Lake river, northward to Roche-qui-trempe-à-l'Eau, these limestones form the mountain exposures, excepting where axes of folds bring up older rocks, as described above. These limestones also outcrop near Wrigley on the east shore and in the small islands, and in the islands above old Fort Wrigley and along the east shore opposite them. Similar limestones form the western slopes of Bear mountain as already described by Kindle.

The limestones are generally dark grey, and at most localities are semi-crystalline and are cut by stringers and veins of calcite, and, less commonly, of selenite. Fossils are widely distributed, but are rarely abundant, and are generally poorly preserved and difficult to collect. Consequently, many identifications are uncertain. The formations intervening between the Middle Silurian and the Middle Devonian strata have not yet been studied, and the inter-relationships are not known. The Mount Kindle region will probably yield this much-needed information to future investigators. The Middle Devonian limestones are overlain by the soft, clay shales of Upper Devonian age described below. The contact was nowhere seen, but the general relationships are well shown in the vicinity of Willow Lake river where the anticline of limestone to the north plunges beneath the shales which are well exposed along the river banks. The thickness of the Middle Devonian limestones is probably between 1,000 and 2,000 feet.

It is not easy to correlate the Middle Devonian limestones of the southern Franklin Mountain region with subdivisions made elsewhere, except that they apparently include Kindle's Beavertail limestone of Bear rock. *Stringocephalus burtini* has not been found by the writer, so that correlatives of the Rampart limestones are not recognized. In a broad way, the faunas closely resemble those of the Onondaga (Corniferous) seas of Ontario, Manitoba, New York state, and Kentucky.

The following identifications have been made from the fossils collected:

From southern end of Franklin mountain near mouth of Willow Lake river: *Phillipsastræa verneuili* Edwards and Haime, a few feet higher in the same section *Favosites nitella* Winchell, *Cladopora* sp., *Ambocoelia* cf. *nana* Grabau.

From a few hundred yards to the north on the mountain top, but probably 200 feet lower in the section, *Cyathophyllum* sp., *Syringopora nobilis* Billings, *S. perelegans* Billings, *Favosites emmonsi* Rominger?. The species here identified has corallites rather smaller and more regular than the descriptions of *F. emmonsi* indicate.

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From the west side of Bell mountain (6 miles east of the river at the mouth of the River-between-Two-Mountains): *Productella spinulicosta* Hall, *Ambocoelia* sp., *Callonema sp.* From 30 feet higher in the same section: *Cladopora* sp., *Productella spinulicosta* Hall, *Cranæna* suggesting *romingeri* Hall and *Loxonema* sp.

Rock outcrops on the islands and on the shore of the river near the site of old Fort Wrigley represent a section of about 120 feet of limestone. The lower 50 feet are thick-bedded and from the upper 10 feet of these beds the following fossils were obtained: *Streptelasma prolificum* Billings, *Favosites emmonsi* Rominger?, *Leptaena rhomboidalis* (Wilckens), *Productella spinulicosta* Hall, *Cyrtina* sp., *Spirifer* sp. In thin-bedded limestone from 50 to 60 feet up in the section the following fossils were found: *Cyathophylloid* compound corals, *Syringopora* sp., *Favosites nitella* Winchell?, *Productella spinulicosta* Hall, *Spirifer davisi* Nettleroth, *Paracyclas elliptica* Hall, *Euomphalus decewi* Billings, *Callonema bellatula* Hall, *Proetus* sp. From the top of the section, the following were obtained: *Streptelasma prolificum* Billings?, *Favosites nitella* Winchell?, *Productella spinulicosta* Hall, *Callonema clarki* Nettleroth, and an undetermined lamellibranch.

The following fossils were collected from a 90-foot westerly facing escarpment of a low mountain 3 miles east of Mackenzie river at Smith creek: *Favosites nitella* Winchell, *Cladopora francisci* Davis?, *Productella spinulicosta* Hall, *Ambocoelia* cf. *nana* Grabau, *Paracyclas elliptica* Hall.

The rock exposed along the east shore of Mackenzie river opposite the lower end of the small island above Wrigley represents 90 feet or more of a section, and from it zonal collections of fossils were made. So little change is evident, however, in the faunal assemblages, that the list is given as one: *Favosites emmonsi* Rominger?, *Productella spinulicosta* Hall, *Paracyclas elliptica* Hall (the last two common throughout the section).

The small rocky islet about one mile above Wrigley contains a section of about 250 feet of blue-grey limestone in a low anticline pitching rather steeply to the south. Zonal collections have furnished the following lists:

Lowest 15 feet of the section: *Favosites alpenensis* Winchell?, *Cladopora dispansa* Davis. From 5-foot coral zone, 65 to 70 feet up in the section *Favosites emmonsi* Winchell?, *Cladopora labiosa* Billings. From 130 feet up in the section: *Favosites alpenensis*, Winchell?, *Atrypa* cf. *reticularis* Linnaeus, *Spirifer tullia* Hall?, *Clinopsitha subnasuta* Hall and Whitfield, cf. *Naticopsis manitobensis* Whiteaves, *Loxonema altivolvis* Whiteaves?

One hundred and sixty feet up and also at 80 feet *Productella spinulicosta* occurs along with *Atrypa aspera* Schlotheim. *Favosites emmonsi?* occurs 205 feet up and *Gypidula galeata* Dalman?, *Rhynchonella tethys* Billings?, and *Proetus* sp. occur in the upper 15 feet of the section.

Roche-qui-trempe-à-l'Eau along the east side of Mackenzie river about 1½ miles below Wrigley is a crushed anticline of grey limestone with axis extending about 10 degrees east of north. The westerly dips average about 42 degrees and the easterly dips 22 degrees. Faults and fractures have relieved the crushing stresses, and sheeted jointing in places obscures the bedding. The rock rises about 1,140 feet above the river and continues northward for about 2 miles as a low ridge, comprising the western limb of the anticline and ending in a knob which includes the east limb of the fold. The stratigraphy was studied along the river, where two sections start at a fault and extend, one upstream with a thickness of 300 feet, and the other downstream with a thickness of between 400 and 500 feet. At the fault, which is nearly vertical and strikes about 7 degrees east of north, secondary selenite occurs in frac-

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tures and between beds of limestone, cutting secondary vein calcite. Some of the selenite veins are 6 inches thick.

The core of Roche-qui-trempe-à-l'Eau consists of crystalline limestone (probably dolomitic) cut by calcite stringers and chert. No determinable fossils were found in it, and the lowest beds exposed are probably not more than 150 feet below the base of the section seen along the river. Still lower beds are probably exposed in the northern end of the range 2 or 3 miles away.

The main ranges of Franklin mountains rise about 8 miles east of Roche-qui-trempe-à-l'Eau, the following fossils being found in the western extension of their foothills: *Syringopora perelegans* Billings, *Cladopora* sp., *Schuchertella* sp., *Productella spinulicosta* Hall, *Bucania* sp.

The above fossil lists indicate a Middle Devonian age for the limestones. Many of the species are common in the Onondaga limestone and its correlatives of eastern and central North America, and some are common in the Manitoba Middle Devonian.

UPPER DEVONIAN SHALES AND LIMESTONES

The Simpson shales, named from the occurrences near Simpson, form the lowest of the Upper Devonian formations of this region. They consist of soft clay-shale of greenish grey or bluish grey colour, containing ironstone concretions. *Buchiola retriostriata* has been found by Kindle and Whittaker in calcareous beds in these shales.

The writer found these shales at a number of localities, viz., in the east bank of the river about 5 miles below Simpson; in Ebbutt hills about 10 miles north of Two-island village; at many localities along the 70 miles of Willow Lake river surveyed; in the east bank of Mackenzie river 2 miles below the site of old Fort Wrigley, and also in the east bank 9 miles below the old fort and opposite the lowest of four islands.[1]

The shale exposures of Ebbutt hills, as measured in a stream bed, represent strata about 650 feet thick, neither the top nor base being seen. No fossils were found at this locality, but ironstone concretions up to 3 feet in diameter are common. These are generally of the turtle-back type, due to shrinkage cracks which are filled with shaly material. The shales here are soft, and appear to lie nearly horizontal.

A number of exposures of soft blue or green shale were seen along Willow Lake river. These are generally much folded and contorted, the shale having been metamorphosd to a phyllite. Two sets of fissility are commonly developed, cutting the shale into small rhombs. At some localities, thin calcareous beds occur in the shales. A few fossils, mostly lamellibranchs, were found in the shales themselves, but they generally disintegrated on drying. Some fossil plants and other remains were found in calcareous beds and are described below. The other outcrops in the river banks gave no further information than that already described by previous writers.

An ironstone concretion found loose on the shore about 40 miles up the river, and evidently from the shales, contains the remains of two Schizopod crustaceans to be described elsewhere.

Two exposures of soft grey limestone occur near water-level in the east bank of Mackenzie river, one about 1 mile above, and one 2½ miles below, the mouth of Root river. From fossil content, this limestone is determined as of Upper Devonian age, and appears to belong just above the Simpson shale formation. The fossils found in these beds are as follows:

[1] Most of the river exposures have already been described by Camsell and Malcolm, Geol. Surv., Can., Mem. 108 and revised edition, 1921, p. 65.

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From locality above Root river: *Productella hirsuta*, Hall?, *Leiorhynchus* cf. *clarkei* Prosser, *Spirifer disjunctus* Sowerby, *Paracyclas elliptica* Hall? At the outcrop below, *Leiorhynchus* cf. *clarkei* is, as at the former locality, the most abundant fossil.

GLACIAL DEPOSITS

Unconsolidated tillite, gravel, sand, and clay occur everywhere over the area. The tillite occurs most commonly at the base of the sections and contains a variety of rock fragments, including granite and other igneous rock, along with limestone of local origin, and pink Cambrian quartzite. The gravel, sand, and clays are evidently glacio-fluviatile, or outwash deposits, frequently showing bedding or crossbedding. At some localities sand lies in channels cut into bedded clay deposits.

Back from the river, glacial ridges of gravel and till rise 100 to 300 feet above the river, and near Two-island village sand dunes covered with jackpine are evidently outwash sand modified by wind action. The sorting is usually poor, however, the frozen condition of the soil in this latitude probably preventing typical wind sorting. The direction of the axes of parallel ridges of till near Smith creek is 10 degrees west of north (astronomic) the direction of glacial action being, probably, at right angles to this direction or from north 80 degrees east.

Glacial erratics, mostly of granite or quartzite, are common on the tops of all the highest mountains visited, showing that the ice-sheet covered the highest peaks, leaving on them its Precambrian debris derived from the old land to the east.

RECENT DEPOSITS

Silt, marl, and moss-peat occur at various places on islands in the river or near the top of the river banks. In islands above the mouth of North Nahanni river, 15 feet of silt contains marl lenses with freshwater gastropods, and thin seams of peat composed of compressed moss and roots. A bed of marl about 1 foot thick extends along the river opposite Wrigley, about 60 feet up in the bank. Such deposits were formed probably in lakes and shallow river expansions before the Mackenzie entrenched its present channel. Small shallow lakes are exceedingly numerous at the present time on the flat land bordering the river.

MINERAL SPRINGS AND TUFA DEPOSITS

Near the fault in the Roche-qui-trempe-à-l'Eau, and at the probable fault location in the island above the site of old Fort Wrigley, mineral springs occur. At the old fort springs issue from the surface of the smaller island about 15 feet above river level, depositing lime over a considerable area. This commonly forms local pools by damming up the water. On the mainland opposite, just above the mouth of a small creek, and about 60 yards away from the shore, lime deposits cover about one-half acre of land, where no trees grow. Small ponds, dams, waterfalls, and brooks result from these tufaceous deposits which encrust moss that thrives in the limy water. The deposits are usually firm enough to walk upon.

At Roche-qui-trempe-à-l'Eau, warm mineral springs deposit considerable calcareous material in the fault zone where it is exposed along the river. One spring issues from a travertine cone about 50 feet above the river. The cone has been formed by the calcareous deposits, and by the talus cemented together by them. The rock on both sides crumbles and falls away, leaving the deposits standing by themselves. The mineral contents of the springs have not been investigated.

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SOILS

Vegetable gardens are cultivated at all the posts and soils varying from clay to sand are found. It is, however, only on the river terraces and on the islands that drainage is sufficiently well developed to yield arable soil.

STRUCTURE

The nearly flat-lying Palæozoic sediments of the Simpson region abut against the foothills structure of Franklin mountains in the vicinity of Willow Lake river. Here the soft Simpson shales have been folded and compressed.

Franklin mountains consist of open-folded limestone and underlying shale, sandstone, and quartzite, with here and there closely folded blocks, relieved in part by strike and cross faulting. On the south, a wide anticline with broken arch appears to have formed the two ridges of the Franklins. Farther north, the deeper, somewhat more complicated structures are laid bare, but even here, simple though rather closely compressed folds are the rule.

METAMORPHISM

As already described, the Simpson shales of the Willow Lake region have been crushed and sheared to fissile phyllites, with two or more sets of highly inclined planes of cleavage. The thin interbeds of limestone are cut by veins and films of calcite. The Middle Devonian limestones are in general semi-crystalline, are almost everywhere seamed with calcite, and near fault planes are cut by veins of calcite and selenite, several inches in width. At the tops of anticlines, as seen at several localities, the limestone is so crystallized and cut by calcite as to be unfossiliferous.

The higher beds seen in the Silurian section are cavernous, evidently due to the solution of gypsum deposits. The coral horizons are semi-crystalline, and chert has developed locally, as a weathering product. The Cambrian quartzites, as their name implies, are sufficiently indurated to be classified as quartzites rather than sandstones.

ECONOMIC MINERAL RESOURCES

CLAY FOR BRICK MANUFACTURE

The Simpson shale, as well as the glacial outwash clays, would probably be useful for brick for local requirements.

LIMESTONE FOR LIME MANUFACTURE

The limestone of the Middle and Upper Devonian formations is suitable for the manufacture of quicklime, so much needed at the trading posts for chimneys and fireplaces.

OIL

As the chief interest in the area lies in its oil possibilities, the various conditions bearing upon its occurrence in commercial quantities will be summarized. No oil seepages were seen by the writer in the Simpson-Wrigley area, nor were the limestones notably bituminous. The Simpson shale is very impervious and would make an excellent cover rock for the retention of oil pools; the beds beneath it, however, are limestone which is not particularly

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porous and consequently not as favourable for oil accumulation as would be a sandstone formation. The structure of the Franklin Mountain region, though in itself rather too intense for oil retention, suggests suitable structure in the outlying areas. The degree of metamorphism, which is largely a measure of the extent of compression, is generally found to have a direct bearing upon oil retention or dissipation. Where extreme metamorphism exists, oils are apt to be fractionated and dispersed through fractures, rather than accumulated into commercial pools. The metamorphism characteristic of Franklin mountains appears, therefore, to be unfavourable for oil accumulation. However, from Simpson to the mouth of North Nahanni river and to the northward in the vicinity of Ebbutt hills, gentle structure or almost flat-lying beds and little metamorphism are the rule, and here favourable conditions may occur for oil accumulation. In this region, however, it is difficult to discover the low arches or anticlines which are most favourable for the occurrence of oil pools, and a number of test wells would be necessary before the possibilities could be definitely determined.

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NORTH NAHANNI AND ROOT RIVERS AREA AND CARIBOU ISLAND, MACKENZIE RIVER DISTRICT

By G. S. Hume

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INTRODUCTION

During the summer of 1921, the writer investigated the country west of Mackenzie river between Simpson and Wrigley, N.W.T. Two rivers, the North Nahanni and Root, both flowing from Mackenzie mountains, were ascended for about 60 miles in each case and a micrometer survey was made. The stratigraphy was studied and data were collected for the preparation of a geological map.

In this work the writer was ably assisted by J. B. Mawdsley of McGill University.

GENERAL CHARACTER OF COUNTRY

MACKENZIE RIVER AND THE IMMEDIATE VICINITY

From Great Slave lake for 250 miles the Mackenzie valley is rather poorly defined. The river flows slightly north of west through a broad, flat plain where low hills on either side of the river, but at long distances inland, relieve an otherwise monotonous, densely wooded landscape. In such a country rock outcrops are few and on the Mackenzie itself the banks are mostly drift material· material. The river flows with a good current in a broad channel broken by many islands.

Two hundred and fifty miles below Great Slave lake there is a change in the character of the country, particularly on the west side. The course of the river is deflected abruptly from northwest to north, this "Great Bend" being caused by the proximity of Mackenzie mountains. The low, flat plain of muskeg, dotted with almost innumerable small lakes, continues up to the foot of the mountains where an abrupt escarpment extends for some miles along the river. The top of the escarpment is 2,000 to 3,000 feet above the plain and the easterly face is unscalable except at a number of gaps where rivers or streams

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have cut through. It is through such a gap or break in the mountains that the North Nahanni flows from the west and enters the Mackenzie about 10 miles above the Great Bend.

NORTH NAHANNI AND ROOT RIVERS

North Nahanni river (Maps 1585 and 1957), except for a short distance at its mouth, flows through a valley with mountains rising about 2,000 feet on each side. It enters the Mackenzie by two channels, one quite small, the other about half a mile wide at its mouth. Its discharge varies greatly with the seasons and when the mountain snow is melting even the daily fluctuation is considerable. During the period of flood there is much undercutting of banks with consequent slumping of material into the river. This furnishes an abundance of driftwood which soon becomes stripped of all limbs and is in places piled into heaps 10 to 15 feet high. When the flood period passes these great masses of driftwood are left stranded on sand and gravel bars or at the heads of islands. Their abundance is striking testimony to the erosive power of a large river in flood.

The great fluctuation in discharge greatly influences its character. During the period of flood the river is often a half mile to a mile wide. The bottom of the channel is everywhere sand and gravel with no rock outcrops except occasionally in the banks, the whole valley floor being made up of pebbles derived from the country rock, and material from a thick cover of glacial drift in the valley bottom. No falls were encountered in the 60 miles of river ascended. The current except at the mouth is everywhere swift, but, owing to the almost complete absence of large boulders in the channel, there are no dangerous rapids. The fall of the river for the 60 miles averages about 7 feet a mile, with over 8 feet for the upper 40 miles, and in many places near the upper end of the traverse 10 and 15 feet a mile were not uncommon. The water is milky-white in colour and cloudy due to fine material in suspension.

In low water the river spreads out in numerous channels which flow through the wide gravel flood-plain. In very few places are these streams concentrated into one channel. Consequently the river is a network of streams surrounding sand and gravel bars, and islands wooded with spruce, poplar, and willows are common in the flood-plain.

The North Nahanni has remarkably few permanent tributary streams. Its basin is simply the narrow valley into which in the spring numerous gorges from the sides carry the great rush of water from the melting snow on the mountain slopes. Later in the summer the gorges are almost invariably dry, or contain insignificant streams. About 20 miles above the mouth, the river divides into two nearly equal branches, one from the southeast, and the other from the northwest. The east branch was mapped and sections along it were studied. A small stream of clear water empties into the Nahanni from the east a short distance below the forks. This is the only tributary of any importance in the part of the Nahanni that was traversed. It derives its water in part from a lake 10 to 15 miles long, situated on the flat plain between the Mackenzie and the mountains to the west. The Nahanni valley through the mountains is scarcely more than a quarter of a mile wide and the mountains on either side rise precipitously to over 2,000 feet above the channel. Through this gap, less than a mile in length, the flow is very sluggish, but beyond, the current is rapid. The structure of the mountains is evidently the controlling factor.

Root river, like the North Nahanni, flows into the Mackenzie from the mountains to the west, but is somewhat different in character. It is smaller

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than the North Nahanni, being not more than a quarter of a mile wide at the mouth and continuing in one main channel for the greater part of the 60 miles which were traversed. Evidence of fluctuation of flow on the Root were even more marked than on the Nahanni, although the amount of stranded driftwood was much less. Driftwood at considerable heights above the stream is evidence that this river, where both banks had been cut, is subject to ice-jams, and that the water under such conditions may rise 20 to 30 feet above the dams. As on the Nahanni, there are no rock falls, but boulder rapids occur in various places between stretches of swiftly flowing water. The fall of the river in 60 miles averaged slightly over 5 feet a mile.

GENERAL GEOLOGY

Description of Formations

—		Thickness
		Feet
Upper Devonian	Shale, zone 3	100
	Athyris angelica zone	200
	Shale, zone 2	1,000–1,200
	Leiorhynchus zone	800–1,100
	Shale zone 1—equivalent of Simpson shale=Fort Creek shale of Norman area	1,000+
Middle Devonian	Bituminous limestone	2,500
Silurian	Non-bituminous dolomite=Lone Mountain dolomite	

SILURIAN

It is not certain that rocks of Silurian age are present in the North Nahanni and Root River areas. The rocks of this age seen elsewhere in the Mackenzie district and on Great Slave lake do not appear in these sections. However, Kindle[1] has reported fossils of possible Silurian age from the base of mount Camsell in the Lone Mountain dolomite. The rocks are very hard, massive, grey dolomites and fossils are extremely rare. No concrete confirmation that Silurian was present could be obtained and the examination of many sections elsewhere in the area did not reveal any evidence of a discordance such as would be expected to occur between the Silurian and Middle Devonian.

MIDDLE DEVONIAN

It was found impossible to subdivide the Middle Devonian in the Nahanni-Root sections. The rocks are a lithological unit and fossils when found are poorly preserved. There are no shale members such as occur farther down Mackenzie river, and divisions could not be made, nor was any sharp dividing line seen between fossiliferous Middle Devonian and the unfossiliferous part below that has been called the Lone Mountain dolomite. A limited number of specimens of *Martinia* sp., similar to those occurring in the Pine Point limestone of Great Slave lake, were found. No doubt this horizon is about the same wherever *Martinia* occurs in the Nahanni-Root sections, but this fossil was not very closely confined in its vertical distribution. Near the top of mount Camsell there is a small series of shales between heavy-bedded limestones and in these shales *Schuchertella chemungensis* occurs at the top of an exposed thickness of 1,550 feet of limestones. The same fossil also occurs on

[1] Kindle, E. M., Geol. Surv., Can., Sum. Rept., 1920, pt. B, p. 44.

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Wrigley rock (Roche-qui-trempe-à-l'Eau) at Wrigley, and on the first mountain to the west of Wrigley. On mount Camsell there is a coral horizon about 20 feet higher stratigraphically than this shale zone. This coral zone contains *Cyathophyllum* cf. *quadrigemum, Favosites, Cladopora, Alveolites,* and *Stromatoporoids.* The same coral zone appears on the top of Lone mountain, an isolated mountain southeast of the junction of the North Nahanni-Mackenzie, and 1,900 feet above it. The thickness of strata represented here above the bottom of the talus is slightly over 2,000 feet. On other mountains to the south of this about 500 feet more strata lie on top of the coral zone so that the exposed thickness for the Middle Devonian and Lone Mountain dolomite is in the neighbourhood of 2,500 feet. The base was not seen.

To the south of Lone mountain there is one of the highest peaks of the Nahanni range which it is proposed to call Nahanni peak. It rises about 3,600 feet above the Mackenzie and the summit is composed of Middle Devonian rocks. The edge shows a well-pronounced thrust fault (Plate III A), and its elevation above the other peaks is believed to be due to this cause. Nahanni peak can be recognized for long distances and is one of the most striking mountain features that greets the view of the traveller down the Mackenzie.

Although there is no definite dividing line of lithological distinction between the Lone Mountain dolomite and the Middle Devonian rocks, there is an easily recognizable general difference between the top and bottom. The lower part consists of light grey dolomite, whereas the upper part is much darker, bituminous limestone. The first member of the Upper Devonian above the top of the Middle Devonian is a dark shale, equivalent to the Simpson shale or the Fort Creek shales of Norman. These shales are in places highly bituminous and in them the Imperial Oil Company sank the first oil well. The dark colour and bituminous odour of the Middle Devonian are no doubt due to bituminous materials that have migrated from the shales above. The rock of the Middle Devonian is much the same throughout the whole Nahanni-Root sections; and to the west of Wrigley, it is a very hard, compact dolomitic limestone that could scarcely be considered a very favourable oil reservoir in this region, because of the metamorphism to which it has been subjected. The porous dolomite of the Presqu'ile formation of Great Slave lake is lacking in the Nahanni-Root River area, although it is probably represented by much less porous dolomites or dolomitic limestones. No *Stringocephalus burtini*—the characteristic fossils of this horizon—were found, but since this fossil occurs on Great Slave lake and in the section north of Norman near Fort Good Hope in the Ramparts limestone, there are probably stratigraphic equivalents in the intermediate areas. In fact, the presence of the coral *Cyathophyllum* cf. *quadrigemum* may have some significance as it occurs elsewhere in the *Stringocephalus* zone.[1]

UPPER DEVONIAN

Shale Zone No. 1. These shales, from their position in the stratigraphic column and their fossil content, agree in age with the Simpson shale at Simpson and with the Fort Creek shales of Norman. They lie immediately above the hard Middle Devonian limestone, the contact between the two being very sharply defined (Plate III B). In the Nahanni-Root River area they are dark fissile shales that weather very readily, and consequently they are little exposed as extensive outcrops. Nahanni river flows over these shales for most of its course, except where it cuts through the mountains, and it is owing to the soft erosive character of the shales that the river is free from rapids and falls.

[1] Report of the second Norwegian Arctic Expedition in the *Fram*, 1898-1902, vol. iv, p. 9.

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The shales are mostly clay shales, dark to black in colour and quite bituminous. Along with them are thin layers of limestone up to 3 inches thick and layers of calcareous and arenaceous shale. Ironstone concretions are abundant in some localities. The shales are mostly unfossiliferous and consequently it is impossible to identify the same horizons in them from place to place. Fossils do occur, however, and quite abundantly in one zone close to the top, where two species of very small *Chonetes* are the most common along with *Atrypa reticularis*.

Owing to the fact that correlation of strata within the formation is hazardous, the thickness is not absolutely known. It is thought, however, to be not less than 1,000 feet and may be as much as 2,000 feet. Where the best exposures occur and opportunity was afforded for measuring the thickness, folding within the shale itself was evident. It would seem that in the process of mountain-building, with the consequent upheaval of the hard, Middle Devonian rocks into anticlinal ridges, the soft shale took up much of the stress. The dips change very quickly in short distances and in a few places the shale itself has been metamorphosed almost to a phyllite.

Leiorhynchus Zone. Leiorhynchids being very widespread and abundant in strata overlying the Simpson shale equivalents, it is proposed to use the name Leiorhynchus zone instead of adopting a new formation name. Sedimentation was continuous upwards from the Simpson shale and, therefore, there is no sharply defined line between the Simpson shale and the Leiorhynchus zone. An arbitrary dividing line is drawn in a series of alternating thin beds of limestones and shales in which the shale becomes increasingly preponderant downwards and the limestone beds become thicker and more abundant upwards until the whole becomes a limestone phase of sedimentation. This limestone, wherever seen, is mixed with a small amount of shale so that the fossils break from the rock very readily and on talus slopes Leiorhynchids especially were easy to collect and free from the enclosing rock. These Leiorhynchids show a striking variation and have a long vertical range, but by their abundance together with the occurrence of other fossils this zone can be definitely identified. A list of fossils provisionally identified appears below:

Leiorhynchus sp.
Camarotoechia contracta. Abundant at certain horizons
Schizophoria iowensis
Spirifer disjunctus. Common at certain horizons and distributed through the whole zone
Athyris angelica. Rare
Rhynchonella duplicata. Rare
A few lamellibranchs, one species of which is quite abundant in shaly facies of this zone.

In this zone was found a coral reef in which a number of fine crinoid heads were discovered. The fauna of this coral reef differs somewhat from the rest of the fauna seen elsewhere and is, therefore, given separately.

Crinoids—25 crinoid heads in a fine state of preservation were obtained.
Cladopora
Cyathophyllum sp.
Diphyphyllum arundinaceum. Abundant
Phillipsastræa verneuili. Common
Phillipsastræa sp.
Aulopora sp.
Eatonia sp.
Atrypa reticularis. Particularly abundant
Atrypa spinosa. Particularly abundant
Hypothyris cuboides
Leiorhynchus sp.
Spirifer sp.

The fauna here described occurs above the shale which is known to be the equivalent of the Simpson shale. The Simpson shale fauna has been shown by

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Mr. Kindle[1] to be the equivalent of the Portage fauna of New York, so that this horizon in which the crinoids occur is younger than the Portage formation. The outcrop of the coral-crinoid reef is about 58 miles up Root river and 2 miles south of the river. Dr. Springer has kindly consented to describe the crinoids found here. The thickness of the Leiorhynchus zone is between 800 and 1,100 feet.

Shale Zone No. 2. Above the Leiorhynchus zone there is another shale facies. Again the line of division is not sharply marked. It is a shaly phase of continuous sedimentation. The lower part is less than 500 feet thick and consists of grey, thin shales alternating with thin layers of limestone. This is followed by a heavy band of massive unfossiliferous limestone only a few feet thick, above which reddish shales occur. These shales have fossils of which the principal one is *Leiorhynchus*. These red shales change upwards to shaly red limestones interstratified with limy shales and in these fossils are quite abundant. The most abundant fossil is *Leiorhynchus* sp., but the specimens from this zone were nearly all very much larger than those found elsewhere. Rarely a *Spirifer disjunctus* was seen. The fossil here referred to *Spirifer disjunctus* may be *S. whitneyi,* because in this zone Spirifer with the fine lines on the striations do occur and are similar to those described as *S. whitneyi* elsewhere. Where the shell is somewhat exfoliated these lines cannot be seen and consequently distinction between *S. whitneyi* and *S. disjunctus* becomes difficult as there is considerable variation shown in specimens of both species. There is another Spirifer—apparently a new species—from this zone which is as far as known confined to these upper red shaly limestones. It has a peculiar shape, being very sinuate on the anterior margin, this giving it a great length in an anterior-posterior direction compared with its narrow width.

A complete list of fossils from this zone is as follows:

Leiorhynchus sp.
Spirifer disjunctus
Spirifer whitneyi
Spirifer sp.

Spirifer disjunctus occurs in the Hay River limestones and shales of Hay River-Great Slave area, and in the Bosworth sandstone of Norman. Until all the faunas are studied in more detail it will not be possible to say how much of the Nahanni Root section is the stratigraphic equivalent of these.

The thickness of the zone measured from the Root River area is not less than 1,000 to 1,200 feet.

Athyris Angelica Zone. This is a relatively thin zone of yellowish limestone with which some grey shaly material is interstratified. The thickness is not more than 200 feet and is probably a little less. Good exposures were found both in the North Nahanni area and in the Root River sections.

The fauna is as follows:

Leiorhynchus sp.
Athyris angelica. Abundant
Spirifer whitneyi
Spirifer disjunctus?
Eatonia sp.
Productella lachrymosa var. *lima*
Ambocoelia sp. Very small fossils—common
Hypothyris cuboides. Two small specimens only

The presence of *Athyris angelica* in abundance is sufficient to distinguish this limestone from the Leiorhynchus zone lower down. The Leiorhynchids that occur in the zone are small and flat and are decidedly different from those

[1] Kindle, E .M., Geol. Surv., Can., Mus. Bull. No 29.

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in the Leiorhynchus zone. From a preliminary study it seems safe to say that the Spirifers most closely resembling *S. whitneyi* occur higher stratigraphically than *S. disjunctus*, although both occur together in intermediate zones.

Shale Zone No. 3. This is a thin shale series, the top of which does not occur in the area. It is a dark, fissile shale, much like shale from the lower part of shale zone No. 2. It was found on top of the *Athyris angelica* zone in the North Nahanni section, in the axis of the syncline, where it has been preserved. Its thickness did not exceed 100 feet and it is unfossiliferous.

STRUCTURE

For the major structure it is only necessary to consider the larger stratigraphic subdivisions, the Middle and Upper Devonian and the Lone Mountain[1] dolomite which has been referred to the Silurian. No definitely determined Lower Devonian was seen in the North Nahanni or Root River sections; and from other parts of the Mackenzie valley, it is known that the Lower Devonian is absent, the Middle Devonian resting directly on the Silurian.

The North Nahanni river near its mouth cuts across Middle Devonian mountains, having flowed through a valley which for about 50 miles from the Mackenzie shows the influence of the rock structure on the course of the river. In this part there is a broad syncline with Middle Devonian exposed on the flanks as high mountains 2,000 to 3,000 feet above the river and with Upper Devonian forming the central part of the syncline. The river throughout this part has closely followed the south and east contact of the hard Middle Devonian limestones with the soft, lower shales of the Upper Devonian, and has been able to erode a deep, wide valley in the limestones and shales of the Upper Devonian. These now form cliffs or abrupt scarps from 1,000 to 2,000 feet above the river on the north side. About 50 miles from the mouth there is a change in the direction of the river where it has cut through hard Middle Devonian rocks which form the mountains on the western flank of the syncline. To the north of this point, the whole section from the Middle Devonian to the highest beds of the Upper Devonian is exposed across the axis of the syncline, although, as elsewhere, the shale members are commonly hidden by the heavy growth of forest and the limestones form cliffs at some distance back from the river.

Following up the river through the Middle Devonian mountains, the mountains themselves are seen to be an anticline with very steep dips on the east slope and with less steeply inclined rocks on the west. Due to the westward dip on the west side of this anticline, the hard Middle Devonian rocks are covered within a short distance by stratigraphically higher rocks which farther from the anticlinal ridge have only a slight westward dip. The river has cut so deeply into these sediments that on both sides high cliffs of Upper Devonian rise 1,200 feet or more above the bottom of the river valley. Viewed from a high elevation, this country underlain by Upper Devonian rocks appears to be a gently rolling plateau with a slight southwestward tilt and deeply dissected by North Nahanni river in its course from the southwest. This part of the river was not traversed, but this elevated plateau stretches for at least 20 to 30 miles to the west and terminates against high cliffs—certainly not of Upper Devonian rocks—that represent the edge of the next westward range. Nothing is known of the country to the south or west, between this plateau and the South Nahanni river, a long distance farther west.

The part of the North Nahanni traversed cuts across two ranges, both of hard, resistant Middle Devonian limestones, one range being about 2 miles from the mouth or junction with the Mackenzie and the other 50 miles up the

[1] Kindle, E. M., Geol. Surv., Can., Sum. Rept., 1920, pt. B, p. 44.

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river. Both of these ranges rise between 2,000 to 3,000 feet above the river and between them lies the great synclinal structure containing Upper Devonian sediments, into which the river draining from the next southwestward valley has cut a deep trench along the strike of the rocks. The river in this part is, therefore, clearly following the structure, having found the line of least resistance along the contact between the hard Middle Devonian limestones and the soft shales of the lowest member of the Upper Devonian.

Root river also follows a structural valley, but one of a slightly different type from that of the North Nahanni. Mount Camsell range near the mouth of the North Nahanni continues with a slight break to the north and is seen as a high escarpment facing east on the west side of Root River valley. Throughout the greater part of this distance it is a fault face. The throw of the fault is some thousands of feet, for the upthrow side to the west brings up the high ridge of massive and resistant Middle Devonian limestones, underlain by the Lone Mountain dolomite into mountains 2,000 to 3,000 feet above the river and the downthrow side preserves some of the highest known Upper Devonian rocks in contact with the Lone Mountain dolomite. The actual contact is covered with talus from the high Middle Devonian mountains, but the dips and strikes leave no doubt about the character of the structure at this point.

About 6 miles above the mouth of Root river, an anticline in Upper Devonian rocks with a northerly strike is cut by the river, and the rocks on the west limb of this anticline dip toward the fault scarp on the west side of the valley. Root River valley is, therefore, on the west limb of an anticline, the river channel being in Upper Devonian strata. About 25 miles from the mouth the direction of the river changes after having cut through the Middle Devonian mountains to the west. The gap in the mountains is very sharply defined, being less than three-quarters of a mile wide, with the mountains rising precipitously on each side to over 2,000 feet above the bottom of the river valley. Upstream from this gap the valley widens to a great flood-plain several miles in extent, and several streams join from different valleys. This is in reality a continuation of the synclinal structure through which the North Nahanni flows for 50 miles above its mouth, but the anticline which made the prominent mountain range to the southwest of the Nahanni has here entirely died out and the structure is a part of the southwestward-dipping plateau which occurs farther up the North Nahanni. The rocks here are gently westerly dipping Upper Devonian sediments, similar to those west of the Nahanni basin.

Evidence of Faulting

There is considerable evidence of faulting on a large scale presumably during the orogenic movements that have resulted in the present mountainous topography.

As already mentioned the country east of Mackenzie mountains is a low plain, lying for the most part little above the level of the river and dotted with almost innumerable lakes and sloughs. The edge of the mountains rises abruptly from the flat plain with an escarpment in many places showing cliffs 1,500 feet high.

There are no outcrops on this flat plain in front of the mountains except along banks of the Mackenzie. A good exposure on the south side of the river about 5 miles upstream from the North Nahanni river consists of rocks of the Leiorhynchus zone. There is an anticlinal structure shown here with a dip down river well indicated. It seems, therefore, safe to say that the plain back of the Mackenzie is underlain by Upper Devonian rocks, probably mostly of

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the Simpson shale horizon, that have been brought in contact with the Lone Mountain dolomite by faulting along the base of the mountains. This would make a throw on the fault of approximately 3,000 feet for this particular section. The escarpment that now forms the eastward face of the mountains is thus the result of erosion along a former fault face. This escarpment shows many evidences of extreme brecciation. The limestone has been fractured and stringers of calcite cutting it in all directions are very plentiful. Brecciation of the limestone itself on a large scale was also noted and is further evidence of the intensity of the forces active in the mountain building.

The eastward-facing escarpment of the main range south of the North Nahanni is continued past Lone mountain which shows similar evidences of faulting. Blocks of fault breccia were seen in the talus slope of Lone mountain. It is evident, therefore, that this fault line scarp is not far removed from the former fault scarp. Between Lone mountain and Mount Camsell range there is a break through which North Nahanni river flows. The east face of Mount Camsell range is also faulted, but this fault trends in a direction slightly different to that of North Nahanni mountains to the south of that river. The faulted face of mount Camsell is continued into the mountain range on the west side of Root river, where the character of the faulting is clearly shown. For miles the escarpment, formed as a result of this faulting, is very prominent (Plate IV A) and is composed of Middle Devonian rocks with the Lone Mountain dolomite at the base. About 20 miles up Root river it becomes less steep and is seen to be a fold with the beds dipping up to 70 degrees on the eastward face. In this folding the evidences of movement are clear and the faulting is apparently a result of further movements that have accompanied extreme folding. At the base of the Root River escarpment, rocks high up in the Upper Devonian sequence occur close to the base of the mountains. The throw here is, therefore, between 5,000 and 6,000 feet.

The range to the west of the North Nahanni, from 20 to 50 miles from the mouth of that river, is of the same type as the Root River mountains. It shows very steep folding (Plate IV B) facing the river, with faulting in places. These mountains are unsymmetrical folds with steep dips on the Mackenzie River side and more gentle dips to the west. In places the beds on the eastward side have become so steeply tilted that faulting is more prominent than folding, but it is quite evident that both have played a large part in the mountain building.

ECONOMIC GEOLOGY

POSSIBILITIES OF THE OCCURRENCE OF OIL

The significance of the work accomplished in the Nahanni-Root River areas lies in the section that has been obtained. In a great many places in the Mackenzie valley only isolated outcrops occur, and it is extremely difficult to interpret the structure. The application of the Nahanni-Root River section to other parts of the Mackenzie River area should prove of great value in solving the structural problems involved in prospecting for petroleum.

In the mountains of the Nahanni-Root River areas the conditions are not favourable for oil accumulation. There is no horizon in the Middle Devonian which would be a suitable reservoir under the conditions of metamorphism to which the rock has been subjected, and any oil formerly in the Upper Devonian beds has probably not been retained in them.

In the flat plain to the east of the front range of mountains, suitable conditions may exist. An anticline on Mackenzie river some 5 miles distant from the mountains shows that there is folding on a moderate scale in this flat

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plain; but the rocks, if they are the same as in the mountain farther west, lack sandstone and very porous dolomite horizons such as would facilitate oil accumulation. It would be an unsafe and unjustifiable conclusion, though, that no suitable horizons exist, because, in the mountains, intensive metamorphism has greatly altered the rocks from the condition they would be expected to have farther east. The area from Simpson west to Mackenzie mountains offers favourable structures for oil prospects but concerning this too little is known of the geology to permit safe conclusions to be drawn in regard to possible oil reservoirs. It is a country overlain by muskeg in which rock outcrops are extremely rare and which is not easily accessible away from Mackenzie river on account of the lack of navigable streams.

TERTIARY PLANT REMAINS COLLECTED BY G. S. HUME IN THE MACKENZIE RIVER BASIN

By W. A. Bell

North side Mackenzie river, about 2 miles up Mackenzie river from Norman:

Sequoia langsdorfi (Brongniart) Heer
Corylus macquarrii (Forbes) Heer
Pterospermites dentatus Heer
Pterospermites spectabilis Heer
Populus arctica Heer
Populus hookeri? Heer
Quercus cf. *olafseni* Heer

West bank Mackenzie:
Acer cf. *aroticum* Heer

All the above species were described by Heer[1] in 1868 and 1880, from the collection made by Sir John Richardson from the lower part of Great Bear river, in 1851, in connexion with his search for Sir John Franklin. They were regarded by Heer, along with other Arctic Tertiary floras, as Miocene in age. Sir William Dawson,[2] however, in 1888-89, in a report on plant remains gathered by McConnell from the same locality in the Mackenzie basin, pointed out the strong resemblance of the flora to that of the Upper Laramie or Fort Union, as well as to the Tertiary floras of Greenland, Alaska, Spitzbergen, etc. He accordingly assigned the Mackenzie beds a Lower Eocene age.

Knowlton[3] in 1904 likewise placed the "Arctic Miocene" flora of Heer in the Eocene (Upper Eocene), and the Mackenzie River beds are referred to the Fort Union group; Penhallow[4] in 1908 came to a similar conclusion in agreement with Dawson's Lower Eocene correlation. On account, therefore, of the close similarity of the Mackenzie Tertiary flora to the other Arctic Tertiary floras it seems safe in the present state of our knowledge to regard the Mackenzie beds as pre-Miocene and to assign to them an Eocene age.

The flora shows a mixture of conifers with such hardwoods as oak, maple, birch, walnut, hazelnut, etc., and hence testifies to a temperate climate in Arctic regions during that part of the Eocene in which it flourished.

GOLD PROSPECTS ON CARIBOU ISLAND, GREAT SLAVE LAKE

Caribou island is situated close to the north shore of Great Slave lake, a few miles east of the southern end of the North arm. For some time gold prospects on it have attracted considerable attention and as the Aurous Gold

[1] Heer, Oswald, Flora Fossilis Arctica, vol. I, 1868, pp. 135-139; 1 Id., vol. VI, 1880, pp. 3-17.
[2] Dawson, Sir William, Geol. Surv., Can., N.S., vol. IV, 1888-89, p. 98 D.
[3] Knowlton, F. H., "Fossil Plants from Kukak Bay," Harriman Exp., IV, 1904.
[4] Penhallow, D. P., "Report on Tertiary Plants of B.C.," 1908, pp. 150-152.

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Mining Company was taking an active interest in the development, the writer was instructed to report on the geology and economic value of the island.

Caribou island is in reality wrongly named. The Indians apply the name to a much smaller island and the one on which the gold claims are staked is known to them as White island or île Blanche. However, since the name Caribou has become so widely known to those interested in the gold claims it seems inadvisable to adopt the Indian name.

Caribou island is one of the larger among numerous islands in this part of the lake. It is said to be 10 miles in length in a general east and west direction. It is quite narrow, however, and as is usual in a country of Precambrian rocks the shoreline is much indented, with deep bays which in some cases extend almost across the island. One of these bays with deep water to the shore offers a very sheltered harbour and is situated close to the Aurous Gold Mining Company's claims. This fine harbour has been aptly named "Safety cove" and any one who has travelled on Great Slave lake, especially late in the summer, will appreciate its value. On the shore of Safety cove the Aurous Gold Mining Company has built a well-equipped and neatly constructed cabin which was used during the winter of 1920-21.

Most of the islands near Caribou island are almost barren of larger vegetation and forbidding in appearance. Caribou island, however, presumably on account of its larger size, has a rolling topography of low hills mostly of rocky character with wide valleys which support a thick growth of small spruce. Near the west end some trees, much above the average size, have been in part utilized in the construction of the cabin. One of the striking features at this part of the lake is the thick growth of white Caribou moss, a lichen which in places is several inches thick and covers what would otherwise be bare rock. Where the moss grows most plentifully trees are generally few.

Attention was directed particularly to the part of the island on which claims have been located. Rocks of only two distinct ages were seen. Of these the less conspicuous are green schists which occur as isolated small patches and which are believed to be older than the other and more abundant outcrops that have been incorrectly called granite. It is a pink arkose containing in conspicuous abundance rounded grains of quartz and pink feldspar. In thin sections quite a little calcite and some sericite are shown to be present as well. The rock is, therefore, of sedimentary origin instead of being igneous. It can be traced laterally by insensible gradations into quartzites. These quartzites are grey and it is in them that the most of the quartz veins occur. The quartz of the quartz veins is readily distinguishable from the quartzites.

Particularly across the part of the island west of Safety cove there is a general alignment of veins in the direction north 40 degrees east magnetic. This is apparently a result of vein filling along a former fracture system which has been responsible for the general arrangement. The rocks cut by the veins, as now visible, are all arkose and quartzites. In places the fracture system is evident only as a narrow zone 8 to 10 feet wide in which the vein quartz has been deposited as a mesh-work of small stringers. Hematite is present and stains the rock red. At other places the quartz veins are spread out over a much wider area and appear on the surface of the outcrop as elongated lenticular masses of vein quartz, no one of which can be traced without interruption for any great distance. In these the quartz is most frequently pure white with much less red stain but with veinlets of specularite. Siderite is also present.

Samples from the same fracture zone as that in which the prospect from which the Aurous Gold Mining Company is said to have obtained gold were

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submitted to the Mines Branch for assay. These samples were taken at various places across the fracture zone and also from individual veins where the fracture system was quite wide. The assays showed no gold. It is only fair to add that owing to the absence from the island of both officials and men of the Aurous Gold Mining Company the particular prospect where gold has been found was not seen. From this prospect very little rock had been excavated and as excavation had been made at many other points on the fracture zone the prospect might be easily overlooked. This was later learned from one of the officials of the company who was accompanying a party on the way to Caribou island when the writer was returning to Edmonton. The conclusion, therefore, is that the Aurous Gold Mining Company obtained the gold from a pocket the extent of which is as yet unknown.

No intrusive rocks were seen, but the east end of the island was not examined. The nearest geological investigation that has been done by the Geological Survey on the Precambrian of this[1] region is in the vicinity of Taltson river which flows into Great Slave lake from the south.

[1] Camsell, Charles, "An Exploration of the Tazin and Taltson Rivers, N.W.T.," Geol. Surv., Can., Mem. 84, 1916.

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GEOLOGICAL STRUCTURE OF THE MACKENZIE RIVER REGION

By D. B. Dowling

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INTRODUCTION

The discovery of oil on the lower reaches of Mackenzie river in a well bored by the Imperial Oil Company, Limited, in 1920, led to the expectation that during the season several more wells would be drilled and that considerable drilling machinery would be shipped in. Existing transportation facilities on the Mackenzie were augmented by several power-boats, yet during the whole season of 1921 material sufficient for building only four standard drilling rigs was transported. Only one drill which was shipped in a knocked-down condition and quickly erected, was operated. This knock-down rig was placed by the Fort Norman Oil Company on the north shore of the river, 8 miles above the Imperial Oil Company's discovery well (Plate V). It was in operation for fifteen days and bored through shale to a depth of 1,500 feet, the limit allowed by the casing on hand. No distinct flow of oil is claimed to have been found; but a flow of gas was reached at that depth and piped to the cabin in which a caretaker was to spend the winter. Three derricks also were in course of erection in the Norman area during the summer of 1921. Drilling at Windy point on Great Slave lake proved that the measures beneath the Presqu'ile dolomite at that place are unproductive.

According to the reports mentioned below, the oil in the eastern section of the Mackenzie region, where the structure shows little disturbance, is heavier than that found in the vicinity of the closer folds of the Norman field. The Norman oil has produced, experimentally, a high-grade gasoline which is almost free of sulphur and passes the test for aeroplane use. The flow of oil in the discovery well, being from shale, declined during the summer of 1921 to a few barrels per day.

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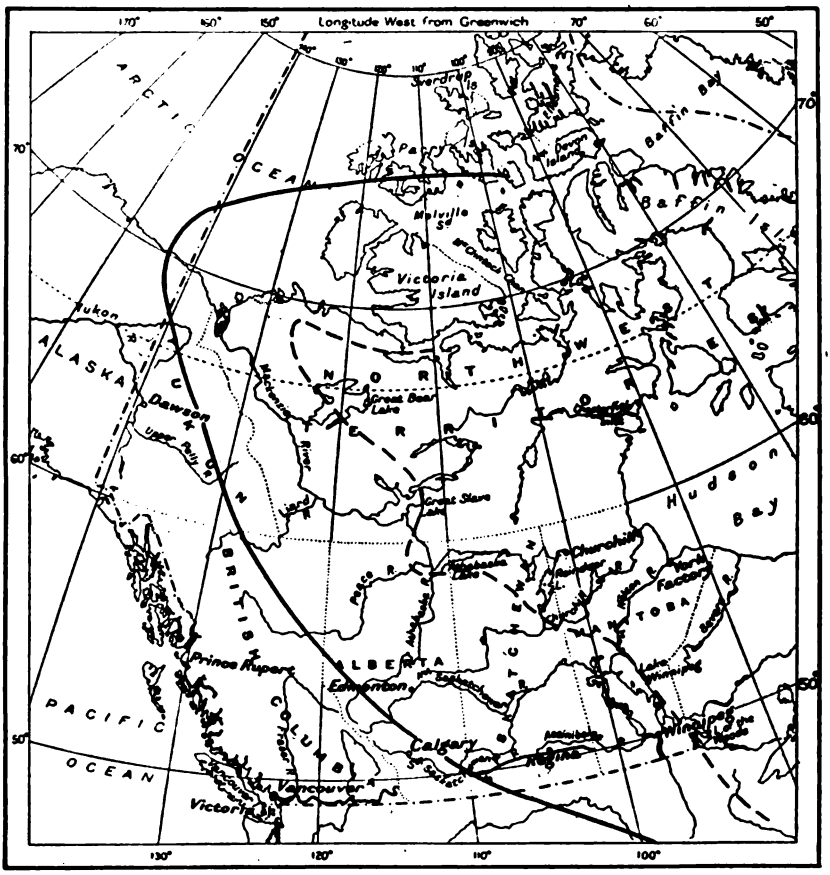
In this report the writer presents certain observations and opinions regarding the structure of the region as a whole which may shed some light upon its oil-bearing possibilities. Local studies of the Great Slave Lake field are contained in the Summary Reports of the Geological Survey for the years 1916 and 1917, and of the Norman field in the Summary Report for 1920. A review of the history of operations in these two fields may also be found in the Second Annual Report of the Mineral Resources of Alberta, 1920, pages 91 to 101.

GENERAL GEOLOGY

SUB-CRETACEOUS SURFACE

The Cretaceous sediments of the Great Plains rest, at their eastern edge, disconformably on Upper Devonian limestones, but, westward toward the Rocky mountains, later Palæozoic sediments are found beneath the Cretaceous.



It is surmised that these later Palæozoics had a western source and were due either to a general uplift or to a tilting whereby the eastern shore-line of the interior sea in which they were deposited gradually moved westward. In Carboniferous time (Figure 1) there emerged a large eastern and northern area

Figure 1. Sketch map showing the western shore-lines of the Palæozoic sea in northwestern Canada. The solid line represents the western shore of the sea in Upper Carboniferous time; the broken line its western shore in Devonian time; and the area between these lines represents the pre-Cretaceous area of erosion.

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of erosion from which early Carboniferous and late Devonian sediments were removed, and in the western part, especially in Alberta, deposition was continuous, though the composition of the sediments indicates a shallowing or a general uplift of this part through Permian and Triassic time. North of the boundary of Alberta and east of the mountains no evidence has yet been found to show that the Cretaceous rests at any point on strata newer than the Devonian.

This sub-Cretaceous surface was subject to erosion as a land area from possibly the beginning of the Carboniferous period. The section in Jasper pass, made up of clastic material largely, is of the earlier Carboniferous period of marine sedimentation. That preserved on Banks island, though largely marine in its upper part, is coal bearing, showing that for a time the early Carboniferous deposits were forming in shallow water. This lends some support to the idea that the nearby Mackenzie area was at this time land. The westward retreat of the sea would also imply a longer period of erosion for the edges of the Palæozoic formations than indicated above and, as Mr. Kindle suggests,[1] that Devonian and earlier sediments were largely removed. In the vicinity of Nahanni mountains the Devonian section is apparently complete, but north and east therefrom the Upper Devonian was largely removed. The pre-Cretaceous surface near Norman is made up of the lower part of the Upper Devonian, but eastward on Bear river it is possible that most of the Devonian was removed, for the limestone exposures appear to be Silurian.

In the Mackenzie basin it would appear that previous to any mountain-building movements, the Palæozoic beds emerged from the sea in much the same manner as is now seen in Great Slave Lake area, that is, in broad bands paralleling their present eastern boundary. Various members were eroded before being resubmerged in the early Cretaceous sea. The material deposited in this sea may well have been derived from extensive areas of the softer beds exposed along its advancing shore, and unconformable relations between the newer deposits and the former land area could thus have been established without earth movements. If there was any folding at this time, it would conform to the general continental structure and might be limited to the ridges north of Bear river near Norman.

CRETACEOUS DEPOSITS

The exact age of the Cretaceous of this basin has not yet been deduced from its fossils. The earliest determinations are probably those by Sowerby, from the fossils obtained from Bear river by Dr. Richardson, naturalist to the second Franklin land expedition. Affinities between the forms found and those known from the oolites of the Oxford clay, were pointed out, and Dr. Richardson[2] suggests that the deposits are probably Lower Cretaceous.

Two fossils brought out by Mr. George Barnston, of the Hudson's Bay Company, were given to H. G. Hind[3] while he was in Manitoba in 1858-59. These were described as new species by Mr. F. B. Meek, palæontologist of the service for the exploration of the United States Territories. Their exact age, however, also the exact locality from which they were obtained, remain indefinite:

"The two ammonites from Mackenzie river are not alone sufficient to determine the age of the rock from which they were obtained; the larger one bears considerable resemblance in form and general appearance to several Jurassic species, though they may belong to the Cretaceous epoch."

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1 Kindle, E. M., Geol. Surv., Can., Sum. Rept., 1920, pt. B, p. 46.
2 "Franklin's Second Expedition to the Shores of the Polar Sea, 1825-27."
3 "Assiniboine and Saskatchewan Exploring Expedition," report by H. Y. Hind, Chap. XIX, 1859.

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Fossils collected by Charles Camsell[1] on Peel river, which flows through the western part of the Cretaceous basin, were examined by Whiteaves, who made no definite determinations, as they were mainly new forms, but listed them as possibly belonging to the following genera—*Panopoea, Thracia, Tellina, Inoceramus,* and two species of *Desmoceras* nearly related to those described from Peace, Loon, and Liard rivers. The formations on Peel river from which these fossils were obtained are no doubt the Loon River shales. In discussing the age of these and the overlying Athabaska sandstones, F. H. McLearn[2] remarks: "Both this formation and the Loon river have a common fauna, and this is now being studied. The affinities of this fauna are Lower Cretaceous (Albian and Aptian rather than Neocomian) and pre-Dakota, taking Cenomanian as the base of the Upper Cretaceous."

The Cretaceous measures which now remain do not appear to be thick, and from the localities cited above they appear to be generally Lower Cretaceous. It is possible that later measures exist in the syncline at the mouth of Mackenzie river. Deposits of Colorado age—the lower part of the Upper Cretaceous—may be represented by *Inoceramus* beds of the upper measures noted by McConnell on Porcupine river, on the Mackenzie above Norman, and by Camsell on mount Goodenough west of the delta. One loose specimen of a *Scaphite* picked up above Norman this season by a member of the topographical survey party headed by Mr. Bowman, seems to confirm the presence of Benton shales.

Later deposits appear to be all coarser sediments, judging by the presence of such formations as the Dunvegan sandstone of Peace river in the section south of Liard river. These in many places are distinctly land deposits, but the absence of fossils in the sands that cap the Mount Goodenough section leaves the question there not decided. The description of the Goodenough section and of that on Porcupine river leaves the impression, however, that they are shore deposits.

Land deposits in the south, and shore deposits in the west indicate a great contraction in the marine area at the close of the Colorado; that is, the inauguration of the general uplift which expelled the Cretaceous sea can be located with some probability at this period for the area which lies north of the boundary of Alberta. An area of erosion resulted to which reference will be made in the discussion of the physiographic details.

It is generally supposed that the debris deposited in the sea during Cretaceous time was derived from a long, narrow land area now represented by the central part of the Cordilleras. The eastern shore of the Cretaceous sea which moved northward and eastward over the Palæozoic floor and reached beyond the existing stratified rocks, would probably receive reassorted material derived from the denudation of the land in that direction. This material would, however, be in small amount east of the Palæozoic beds, for the Precambrian area in that direction had been already cleaned by long exposure and there appear to have been no great disturbances to elevate it. There is little of this material in the edge of the present Cretaceous terrace. In the vicinity of Great Bear lake and on Mackenzie river the deposits have characteristics which suggest that they originated from the underlying sandstones and shales or from beds that outcropped during the advance of the shore-line. Other deposits—especially those reported on Great Bear lake—seem to be of material derived from a land area consisting of harder and more siliceous materials.

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[1] Geol. Surv., Can., Ann. Rept., vol. XVI, pt. CC, p. 48.
[2] Geol. Surv., Can., Sum. Rept., 1917, pt. C, p. 16.

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Judging by the description of the deposits west of the mouth of Mackenzie river the material brought to the sea was thickest in that direction. Hence, with the shallowing of the sea in the east by continental uplift, the upward movement in the west under the greater load may have been retarded; or the removal of the thinner shore deposits of the east may have commenced while the deposition of the upper sands continued to the west. With the meagre fossil evidence at hand we can only assume that the denudation of the north-eastern edge of the Cretaceous deposits commenced before the Colorado period. This would allow of continuous erosion of this northern part following its elevation.

The topography previous to the formation of the mountains and the deposition of the Tertiary beds can only be inferred. On Wind river the Cretaceous rocks were eroded to the Devonian, and eastward to the Ramparts a mass of Cretaceous was probably preserved in a shallow synclinal trough. Southward the present configuration of the Rocky mountains and the far extended anticlinal ridges suggest that no great load of loosely assembled Cretaceous material lay on the hardened Palæozoic beds.

TERTIARY

The Tertiary beds overlying the Cretaceous at Norman, distinguished by containing burning beds of lignite, are undisturbed by the forces which elevated the steep anticlinal ridges in the older formations of the vicinity. They are slightly tilted, but abut directly against the broken and elevated eastern end of Bear rock. They contain a fossil flora that has been assigned by European writers to the Miocene. Sir Wm. Dawson, after describing the flora of the freshwater deposits which lie conformably above the Cretaceous of Alberta and Saskatchewan, correlated these northern beds with the Laramie, that is, with the early Eocene of Canada. As there is an erosion interval beneath the Norman beds, Dawson's correlation depends entirely on the plant remains. The similarity of floras is equally marked between the plants of the Norman beds and those of the Miocene of Greenland. The fact that the foothills and outer mountain ranges of Alberta were upthrust in late Eocene time also indicates a Miocene age, at least, for these Norman beds, since they are undisturbed. However, Camsell found on Wind river, west of the Norman area and near the mountains, that similar Tertiary beds are there deformed by pressure. In physical condition, the northern beds are, therefore, like the Eocene beds farther south, slightly tilted at a distance from the mountains and more folded on approaching the disturbed zone of the mountains. The latest mountain building, as determined by evidence in Alberta, was at the close of the Eocene, so that the above observations on the physical condition of the northern Tertiary deposits imply an Eocene age and corroborate Sir Wm. Dawson's views.

STRUCTURAL GEOLOGY

The mountains on either side of the Mackenzie valley below Liard river are at variance in some respects with the ranges found along the western border of Alberta. The rectilinear Alberta ranges give place in the north to a rather divergent series which projects farther eastward, almost across what has been called the Rocky Mountain geosyncline. The Alberta mountains are formed from the fractured and folded extra-thick beds of the western part of this geosyncline. The northern mountains, on the other hand, are formed from much thinner deposits that overlie the Precambrian; and they present

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phenomena which suggest that in their formation a comparatively thin sheet of the stratified crust was crumpled by compressive strain. The northern mountains, particularly those near the outer eastern margin, appear to have been elevated before the Tertiary beds at Norman were deposited. Accepting Sir William Dawson's opinion that these beds are Eocene, and considering the apparent deformation of the Cretaceous, it would seem that the northern mountains were formed early in the period of crustal compression which was inaugurated towards the close of the Cretaceous. They, therefore, antedate the outer ranges of Alberta which were formed at the close of the Eocene.

As mountain building involves movements of wide extent, these two mountain-building operations no doubt each affected the mountain structure of both regions. The effect of the early Eocene or late Cretaceous movement in the north is shown in the ridges near Norman, the main ranges of the Mackenzie mountains, and in the formation of the basins holding Tertiary beds in the Yukon plateau to the west. The effect of the post-Eocene movements is shown

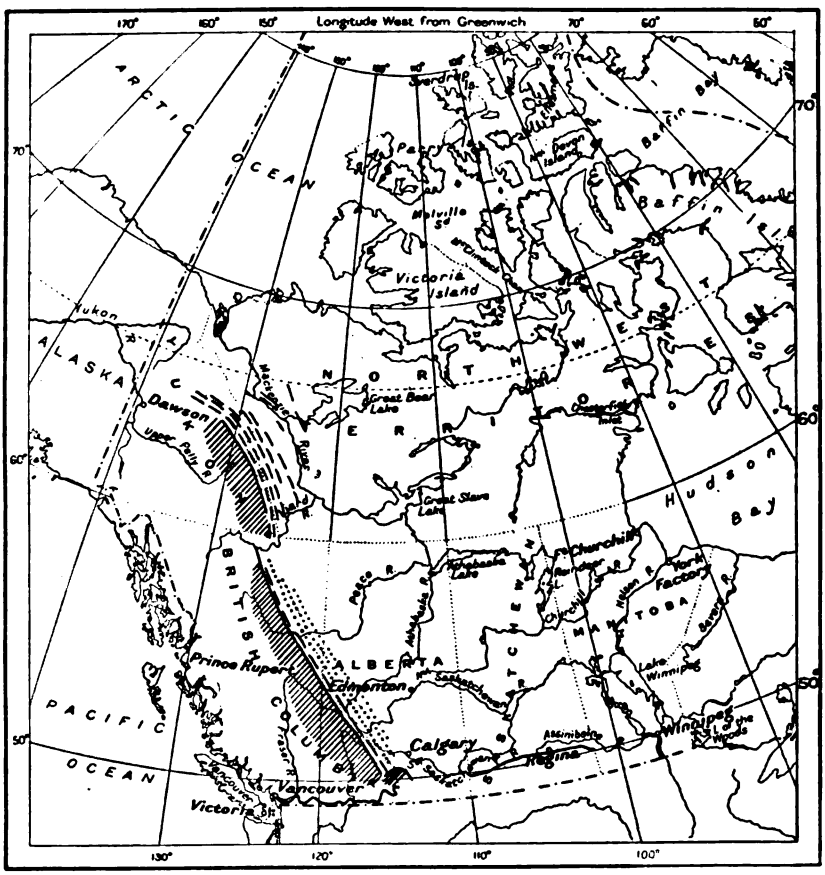

Figure 2. Sketch map of the Eastern belt of the Canadian Cordilleras, showing: (*a*) area of uplift, normal faulting, and trenching, in oblique line shading; (*b*) area of compression and overthrust during late Cretaceous time, in broken lines; (*c*) area of compression and overthrust during late Eocene time, in dotted lines.

in the overthrusts of the outer Rocky mountains, in tilting of the Tertiary beds at Norman, and in folding of the Tertiary beds of Wind River plateau to the west. The order of formation within the two groups of mountains

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seems to have been opposite in direction. The Rocky mountains, originating in a series of large fault blocks followed by the formation of overthrust fault blocks that formed mountain ridges to the east, show a progression from west to east. Mackenzie mountains, with which may be grouped Franklin mountains, originating with crustal movements and folds followed by the regular Rocky Mountain type of thrust fault blocks, show progressive development from east to west (Figure 2). The sediments in the Rocky Mountain geosyncline, as exposed in the several ranges, are much thicker than corresponding beds in the plains to the east. This greater thickness, and the coarse composition of these sediments, indicate a western derivation.

During the long period from the earliest Cambrian and to the close of the Carboniferous, there was steady erosion of a western land area, but there is little evidence in this time of mountain building. The great mass of sedimentary material laid down in the sea shows merely a gradual expansion and contraction of this sea, from a maximum—probably in Silurian time—to a minimum at the close of the Carboniferous.

Strains then followed which were continental in extent and caused an elevation of the western part of the continent which reached a maximum at the close of the Palæozoic era, and may have been general enough to disclose the unequal loading of this ancient sea-bottom. The normal faulting found in the Selkirks and even eastward may have commenced at an early date, although Jurassic batholithic intrusions[1] of the Pacific coast and southern interior of British Columbia represent the period of adjustment.

There are indications in the Cretaceous deposits of revived denudation of the land area to the west, and of a depression of the central part of the continent, to allow of the invasion of the Cretaceous sea which reached a maximum for the southern interior of the continent during the Colorado period. Very coarse conglomerates appear along the western margin, covering the marine Jurassic beds and in greater amount the land deposits of the early Cretaceous. These conglomerates in turn in the vicinity of Coleman are overlain by erupted material, probably the best evidence in the Cretaceous of a nearby elevated land area and of probable differential movements of the land concurrent with the sinking of the eastern area beneath the Cretaceous sea. The first marks changes in elevation at the close of the Jurassic which affected the land areas; the second the inauguration of a greater subsidence occupied by the sea during late Cretaceous time.

The fault blocks forming what may be described as the British Columbia portion of the Rocky mountains are separated by fractures of generally high dip. The various elevations of the mountains during Cretaceous time can, therefore, be attributed not so much to lateral pressures as to the deeper-seated forces which caused the elevation of the land mass of the central part of the Cordillera and the sinking of the eastern geosyncline. These blocks have been so greatly eroded that their elevation must antedate by a long period the fracturing which produced the slip planes for the series of overthrust blocks which form the eastern Rocky mountains.

There seem to be two physical causes for these mountain areas, an earlier one of isostatic adjustment just mentioned, and a later one of crustal compression. Certain foldings observed in these early fault blocks that are not involved in later faultings of the overthrust type are certainly due to compression. The probable re-elevation of the eastern series of blocks relative to those to the west seems also to have been due to compression. This re-elevation of the marginal blocks established structural lateral channels and greatly

[1] Schofield, S. J., "Origin of Purcell Trench," Trans. R.S.C., vol XIII, 3rd series, Sec. iv, p. 28.

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changed the lines of drainage.[1] The valleys so formed and sculptured are older looking than the denuded channels that were cut through mountains formed during the early Miocene period of stress. The revived drainage into the Mid-Cretaceous sea may date from a period of pressure which caused the changes in the eastern margin of the Cretaceous sea (Figure 3), and the change in the sediments noted above. The later Cretaceous sediments indicate a nearby erosion area. The early Cretaceous that is preserved in the outer mountains, though a land deposit, is only occasionally of coarse material and represents the erosion products from land elevated during the close of the Jurassic. Marine beds to the east and north are finer sediments.

The Mid-Cretaceous disturbance is marked, as noted elsewhere, by heavy beds of conglomerate covering the early Cretaceous near the mountains. The retreat of the Cretaceous sea is marked by changes in sedimentation that show

Figure 3. Sketch map showing northern uplift in western Canada during late Cretaceous time. The stippled part with broken-line boundaries represents the area submerged during the advance of the sea in Lower Cretaceous time, the unstippled parts representing islands. The two solid-line boundaries define areas of marine retreat during Upper Cretaceous time.

an irregularity in the movement and no doubt indicate minor periods of stress and probably some deformation as well. It is probable that most of the material which reached the Cretaceous sea in its later stages was removed from the

[1] Schofield, S. J., "Rocky Mountain Trench," Trans. R. S. C., vol. XIV, 3rd series, Sec. IV, p. 62.

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immediate front of the mountains, and the large amount of this material suggests that former shore deposits were being redistributed from a rapidly rising land surface.

The Eocene deposits indicate no great disturbance. The general Eocene uprise is shown by the activity of the rivers in bringing material eastward from the fractured and elevated tributary land. This is marked by abundant crossbedding in the great sand deposits that were laid down in thick beds. The close of the Eocene is generally credited with the maximum uprise and surface displacement, the inauguration of volcanic outflows marked prominently in maps of southern British Columbia, overthrusting at the edge of the preexisting mountains, the formation of new mountains in the fractured zone, and the deformation of the Eocene beds along with the underlying formations.

The deposition of coarse sediments, mainly conglomerates, on the plain far to the east of the mountains, is attributed to the denudation of the newly risen mountains. The summit of Cypress hills exhibits this material. Vertebrate remains discovered in the debris point to the age as Oligocene. The last mountain building is thus placed at the close of the Eocene and, probably, was contemporaneous with the period of vulcanism in British Columbia, which is placed in early Miocene time.

NORTHERN RANGES

North of the sixtieth parallel the mountain ranges do not lie along the western edge of the great geosyncline, as in Alberta, but cross the geosyncline northward to near its eastern edge. The sediments are greatly reduced in thickness as compared with those in the south. There was a lessening in the amount of sedimentation, and a total lack of it from Carboniferous to early Cretaceous time. Denudation probably lasted from Carboniferous to Cretaceous time (Figure 2). Cretaceous sedimentation was also limited to the early part of the period. The foundation material for the formation of these northern mountains seems, therefore, to be quite different from that in the area of normal faulting in Alberta.

A great part of the northern mountain structure seems to be limited in time to the periods of compressive strain in the ranges to the west and in Alberta. In Yukon granitic batholithic intrusions are found in the western part of Mackenzie mountains and are tentatively held to be of Cretaceous age. They are intimately associated with the earlier intrusions of the Coast range, but although very similar, lithologically, they were apparently intruded somewhat later. During the period of subsidence marked by the spread of the early Cretaceous sea over this part of the continent there was little other disturbance. The elevation of a large area in the north over which there seems to have been little deposition of Upper Cretaceous sediments, may have been accompanied by some folding and intrusion. D. D. Cairnes found evidence of the intrusion of the Laberge series by the granite in Atlin[1] and White River districts,[2] which indicates some of the intrusion to be post-Lower Cretaceous. Evidence of the deformation of the Cretaceous before Tertiary time is contained in the following quotation:[3]

"During early Tertiary time freshwater sediments were deposited throughout considerable portions of Yukon and Alaska. These beds were apparently, for the greater part at least, deposited in isolated basins, and now consist mainly of friable, partly consolidated sandstones, shales, and clays, which in places contain seams of lignite. In Upper White River district these beds,

[1] Geol. Surv., Can., Mem. 37, p. 69.
[2] Geol. Surv., Can., Mem. 50, p. 95.
[3] Cairnes, D. D., Geol. Surv., Can., Mem. 50, p. 115.

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which are considered to belong to the Kenai series, have only a slight development but occur through three small areas. They are nearly flat-lying wherever exposed, and are thus contrasted with the Mesozoic sediments which are extensively and in places even minutely deformed, closed folding being characteristic of the structure in many localities."

Apparently, therefore, the country west of the Mackenzie was deformed and invaded by granite between early Cretaceous and Eocene times. The mountains between Mackenzie and Yukon rivers may have been outlined at this early period, and the early Miocene disturbances may have been confined mainly to the uplift of the Yukon plateau, minor changes in elevation of the mountains, and to a mild deformation of the Tertiary beds.

The early Miocene disturbances, because of their magnitude, would be the first to be credited with mountain building in the north were it not that disturbed Eocene beds lie against folded Palæozoic rocks at Norman and against Mesozoic beds on White river in Yukon. A pre-Cretaceous age can not be assumed for the mountains unless great unconformities can be found beneath the Cretaceous at more favourable places than at this distant point. In the Rocky mountains the Kootenay formation lies conformably above the Jurassic at the top of a complete section. On lower Athabaska river slight undulations in the Devonian overlain by the Cretaceous may be, and probably are, the result of later strains. Finally, in Mackenzie valley the Cretaceous measures appear to be conformable with the underlying Palæozoic rocks and are folded with them.[1] Mr. Link, of the Imperial Oil Company, informed the writer that on Little Bear river, west of one of the pitching anticlines, the Cretaceous conforms with the anticlinal structure; also, that west of Franklin range and Mackenzie river the prevailing dip in the Cretaceous is to the west away from the range. The eastern ranges were largely constructed between the period of uprise in the late Cretaceous time and the deposition of the Eocene sediments. Little is known of the earlier mountain structure which lies to the west. Older mountains or land areas no doubt existed, as in the south, but probably did not attain as great elevation; nor were they of the same block formation. Keele's[2] description of Mackenzie mountains contains the following summary: "The topography of the western portion bears evidence of long-continued differential erosion while the eastern portion has the appearance of being in a more youthful topographic stage. Both in geology and structure the eastern portion of these mountains is closely related to the Rocky mountains in southern Canada."

LATE CRETACEOUS SEDIMENTATION AND DENUDATION

The Cretaceous rocks on Peel river are predominantly sandy. A section measured by Camsell[3] near the mouth of Mackenzie river shows the lower shale series capped by a thick sandy formation which represents the later Cretaceous deposits. Whether this was deposited in the sea or is a delta deposit can only be inferred. Its proximity to the present coast suggests marine deposition. It was evidently derived from a nearby land area. As there are other evidences of an uplift in the north dating from the middle of the Colorado period the land area no doubt formed a broad band in front of the older mountains, over which the debris from the mountain area was spread. The maximum uplift was probably within the area denoted on geological maps by the absence of Cretaceous deposits, that is west of Great Slave and Great Bear Lake basins. An ancient land area was thus formed between the southern Cretaceous sea and Arctic waters. The shore deposits of the sea which retreated south have

[1] See Plate VI.
[2] Geol. Surv., Can., Pub. No. 1097, p. 18.
[3] Geol. Surv., Can., Ann. Rept., 1906, vol. XVI, pt. CC, p. 46.

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been largely removed except along its western shore-line, represented by the broken areas of the foothills. There are some masses of coarse sediments, however, which may have been derived from the land barrier to the west (Figure 3). The Dunvegan sandstone, the Wapti formation, and the Edmonton formation, all of which decrease in thickness to the southeast, are examples of the Cretaceous sand formations, which in their southern extension lose this character.

Pre-Tertiary denudation of the Cretaceous measures in the northern basin may have been complete in certain elevated parts, for example, in Wind River basin where the Tertiary rests directly on upturned Devonian beds,[1] or on the northward slope and near the crest of the Cretaceous land barrier, where the continued removal of material may have reached down to Devonian beds. In less elevated areas, the measures covering the Palæozoic floor include beds which seem to have been deposited before the uplift. These are the marine shales above Norman containing *Inoceramus* and *Scaphites* and supposed to be of Colorado age.

Continued uplift expelled the Cretaceous sea from the present continent, after which followed a period of tranquillity through Eocene time. Mountain building which did not deform the Eocene deposits but is recorded in folding and tilting of the Cretaceous must, therefore, have taken place during the period in which the land areas assumed their present extent, i.e., the close of the Cretaceous period.

This late Cretaceous activity is not registered along the Alberta ranges, although fractures with low horizontal dip may have been formed and masked beneath the incompetent mass of Cretaceous sediments, which were largely of continental formation. Surface movement probably spent itself in overthrusting and in the elevation of this unconsolidated mass. Northward the conditions were changed by the introduction of granitic intrusions in the area to the west, the denudation of a large part of the crustal load, and by the presence near the surface of competent beds to transmit compressional stresses. The strains of this period were thus locally greater and were transmitted much farther eastward than in Alberta. The character and extent of the resultant folding suggests that the plane of sliding was not a deep one. The margin of the disturbed belt north of Liard river includes a triangular area bordered by ridges or folds. The east side bears nearly north to beyond Great Bear river. The north side extends in a slight northward curve, from a plateau remnant of Cretaceous at the mouth of Mackenzie river eastward to meet the line of folding that forms the eastern boundary. The western side of the triangle consists mainly of folds and possibly overthrusts bowing inwards, each succeeding westward range straightening this alignment. The western ranges are not yet definitely outlined nor is their history known. The structure outlined by Keele[2] exemplifies the prevailing folding of Mackenzie mountains.

MOUNTAINS EAST OF MACKENZIE RIVER

The eastern edge of the area affected by mountain building consists of several close folds lying *en échelon* and forming Franklin mountains (Plate VI). The structure shows the effect of a lateral pressure and also of a relative northward movement of the crust on the west side of these mountains. This line of movement may perhaps be compared with the line observable between the current of a stream and the backwater caused by an obstruction. In this case the area east of the line of movement was protected behind the Cretaceous plateau. The movement of the crust was through the gap between the Liard plateau and the Peel plateau. The line of deformation should,

[1] Geol. Surv., Can., Ann. Rept., 1904, p. 41 CC.
[2] Keele, J., Geol. Surv., Can., Pub. No. 1097.

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therefore, be somewhat arc-like, but as the direction of strain appears to have been from the south for the first part of the movement, a different alignment was actually produced. The most northern fold bears nearly east and west, normal to the direction of pressure. The eastern folds show the effect of a lateral strain. Following the elevation of the ridges along the east side, the resistance offered by the accumulating weight in the folds deflected the zone of stress westward and developed a zone of shearing. The parting of the crust along the western side of this shear zone allowed further northward movement and several concentric folds were formed along the northern edge, ending abruptly at the shear zone. The succeeding movements produced more extended folds which appear to have been caused by pressure from the south-west. These form the western edge of the triangular area referred to already and the succeeding movements of the crust produced additional steeper folds lying against them to the westward.

NORMAN PLAIN

An almost level plain extends between the general mass of the Mackenzie mountains and the outer edge of the mountain-built area described above. It is in some parts about 30 miles wide and is presumably underlain by rocks that are not sharply folded. Bedrock is masked by vegetation—spruce, willows, and moss. Near the river there appears to be a cover of drift but the higher ground, back from the stream, may expose some of the hard bedrock, which is probably largely Cretaceous, although, as compression of the beds has produced an irregular series of buckles, occasional exposures of the Palæozoic beds may be expected.

The plain seems to be divided into two parts by the inferred line of shear (Plate VI).

The eastern part, which contains Mackenzie river in its course above Norman, is probably crossed diagonally by several buried ridges and hollows and is depressed in the vicinity of the ends of the ridges normal to the Franklin range. The southern part of this strip is narrow and may be merely a syncline between the mountain ridges on either side of the river. West of the shear zone the Norman plain shows a few ridges which may be structural. Near the northern border the dip of the beds into the basin rapidly flattens and it is surmised that a wide area is available for prospecting with the drill, as the basin does not appear to be deep.

Determination of the structure will depend on the determination of the Cretaceous section, for these beds probably rest almost conformably on the pre-Cretaceous formations. A determination of the thickness of the Cretaceous to be drilled through will, therefore, help in estimating the probable depth to the oil horizons in the Devonian. The westward extent of this basin as an oil field is not determined. Westward of the end of the ridges bordering the Mackenzie on the north, the plain seems to extend far, since no mountain chain can be seen from the river. It may be, however, that the measures dip beneath an added thickness of Cretaceous, as they do on the Mackenzie below the Ramparts, and that the available oil field is restricted in that direction to a zone bordering the mountains to the south. Mr. Link found along these mountains the upturned beds from the basin as on the north side, so the structure of the plain is probably that of a flat basin with its edge upturned on two sides.

Deep depressions such as would be possible along the shear zone or in the centres of synclines would form basins for the collection of debris during Eocene denudation. The presence of Eocene beds should, therefore, indicate areas where the Middle Devonian beds are at a maximum depth.

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KANANASKIS LAKES-PALLISER RIVER MAP-AREA

By J. R. Marshall

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INTRODUCTION

During the field season of 1921, the writer continued the structural and stratigraphic mapping of the Kootenay coal-bearing rocks and associated formations on the eastern slope of the Rocky mountains. Up to 1920 this investigation covered the territory comprising the eastern and western slopes of the Rocky mountains in Alberta, south of parallel 50° 30′ north latitude. From June to October, 1921, mapping was carried northward into Kananaskis Lakes-Palliser River map-area, special attention being devoted to the areas in which economic deposits of coal occur or are likely to be found. Such areas are the south branch of Sheep creek, in the upper 6 miles of its course; the valleys of Mist and Storm creeks (the headwaters of Highwood river) and Pocaterra creek, flowing to Kananaskis river.

Very efficient assistance was rendered in the field by J. Drybrough and M. L. Urquhart.

Sincere thanks are also tendered to Mr. P. Burns and the officials of the P. Burns mine for the many courtesies extended during the season.

The area explored may readily be reached from Okotoks, on the Calgary-McLeod branch of the Canadian Pacific railway, or direct from Calgary by automobile. A good wagon road is available from Okotoks to the P. Burns coal property on Sheep creek,[1] about 45 miles. Automobiles commonly travel to within 10 miles of the mine, the remainder of the distance being covered by wagon. From the P. Burns property good pack trails lead to the various parts of the area.

GENERAL GEOLOGY

The stratigraphic column consists of an apparently conformable succession of rocks ranging from Devono-Carboniferous to Upper Cretaceous. The rock succession and lithological and structural features are in the main similar to those of the northern part of the Crowsnest coal field, and Highwood River coal area, both of which have been described in previous summary reports.[2]

The Kootenay formation carries all the workable coal in the area examined and alone is described in detail here:

Table of Formations

Pleistocene and Recent	Superficial deposits
Upper Cretaceous	Allison formation
	Benton formation
	Blairmore formation
Lower Cretaceous	Kootenay formation
Jurassic	Fernie formation
Triassic	Upper Banff formation
Devono-Carboniferous	

[1] The Geographic Board now applies the name Sheep creek to the branch formerly known as the South branch.

[2] Geol. Surv., Can., Sum. Rept., 1918, pp. 13 C-16 C; 1919, pp. 14 C-20 C.

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KOOTENAY FORMATION

The Kootenay formation maintains its typical aspect across the area. It is characterized by crossbedded grey sandstones, dark shales, and intercalated coal seams. The prominent conglomerate band, at the top, which in the area to the south separates the productive Kootenay measures from the non-productive Blairmore formation above, is present, wherever the Kootenay is overlaid by younger formations. As in the adjacent Highwood River area, and the Crowsnest field farther south, the Kootenay of the Kananaskis-Palliser area contains extensive and important coal deposits not too far distant from existing railways. The measures have been prospected on Picklejar creek at the southern border of Kananaskis map-sheet; and on Pocaterra creek, across the divide separating the Highwood and Kananaskis waters, and have been considerably developed on the Burns property, Sheep creek, where the most extensive exposure of the measures may be seen. This exposure, 6 miles from the source of the creek, is the easternmost band of the area and forms the western slope of Highwood range. It extends south across Picklejar creek and connects with the easternmost band of Highwood River coal area. From the Burns mine westward across the Highwood range, the Kootenay formation is four-fifths of a mile wide. Northward along Sheep creek the width increases up to 1¼ miles on the north side of Burns creek, beyond which the band is greatly restricted and at the head of Sheep creek disappears entirely, where its limestone is thrust eastward upon Fernie shales.

The continuity of the band just referred to is worthy of note. From the Crowsnest area northward across the Oldman-Highwood River divide three main bands of Kootenay measures are exposed almost continuously.[1] Two of the bands cross the Highwood area, this particular band being the easternmost. There is, therefore, a continuous exposure for about 100 miles from Crowsnest pass to the head of Sheep creek.

A second band of Kootenay measures outcrops on the west side of Mist Creek valley. North of the head of Mist creek it joins the band from P. Burns mine. Southward it continues across the tops of the ridges on the west side of Mist creek to the junction of Storm and Mist creeks, where it unites with a band from Storm creek to form the western band of the Highwood area.

The band on Storm creek continues across the divide into Pocaterra creek where it forms a high sandstone ridge along the western side of the creek. About 5 miles from the head of Pocaterra this band crosses the creek and continues northward as a narrow belt between two limestone ridges which appear to unite in a distance of 10 miles.

ECONOMIC GEOLOGY

Coal is the only mineral of economic importance in the district. All the workable coal is contained in the Kootenay formation, and is the high carbon bituminous variety, so characteristic of the eastern slope of the Rocky mountains in southern Alberta. There are no working mines in the area; for transportation facilities are limited to wagon roads, and the nearest railway is 45 miles distant. A preliminary survey for a railway has, however, been made along Sheep creek to the P. Burns mine, and a right-of-way has been cut.

Considerable prospecting has been done over the band of Kootenay rocks which extends from the head of Sheep creek along the western slope of the Highwood range and across Picklejar creek to connect with the easternmost band of Kootenay rocks in the Highwood River area. Coal seams have also

[1] Geol. Surv., Can., Sum. Rept., 1918, p. 16 C.

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been opened up in the Kootenay rocks on Pocaterra creek. No prospecting appears to have been done along the western side of Mist creek, nor on Storm creek, on both of which are numerous showings of coal. The measures, however, are more broken by faulting and more intensely folded than in the prospected areas and are, therefore, less adapted for mining on a large scale.

On the P. Burns property coal seams have been uncovered on almost all the west tributaries of Sheep creek in the upper 6 miles of its course. A tunnel driven for 2,250 feet across the measures cuts twelve or fourteen seams of coal ranging in width from a few inches to 39 feet. There are at least seven workable seams, the first of which, 1,376 feet from the tunnel entrance, is reported to be 39 feet thick. At 1,500 feet from the portal there is a 21-foot seam. Neither of these seams could be conveniently sampled. Both dip 75 to 80 degrees west and the coal where the absence of timbering permitted a view was considerably crushed and broken.

At 2,200 feet from the entry a seam 12 feet wide was crossed. In it the coal is of the lump variety and considerably harder than the coal in the first two seams. There are 8 feet of clear coal and the remaining 4 feet contain two bands of shale, 1 inch and 2 inches in thickness. These, however, can readily be separated from the coal. A selected sample was taken from this seam, also a channel sample across the entire width, but both bands of shale were omitted. Below are given results of analyses made by the Mines Branch.

Analyses

—		1	2
Proximate analysis:			
Moisture	%	0·4	0·4
Ash	%	4·4	13·9
Volatile matter	%	16·4	14·7
Fixed carbon (by difference)	%	78·8	71·0
Ultimate analysis:			
Sulphur	%	0·9	0·9
Calorific value in B.T.U. per lb		14930	13250

1. Selected sample—forms poor coke.
2. Sample across seam—agglomerates.

On Sharp creek, the first creek tributary to the Sheep, northwest from the main tunnel, a number of shorter tunnels cut the same seams that are intersected in the main tunnel. Some of the tunnels still afford access to the coal, of which there are at least 70 feet workable. A sample from one of these seams, 15 feet in width, was analysed by the Mines Branch, Ottawa, with the following result:

Proximate analysis:[1]		
Moisture	%	0·5
Ash	%	15·4
Volatile matter	%	13·4
Fixed carbon (by difference)	%	70·7
Ultimate analysis:		
Sulphur	%	0·4
Calorific value in B.T.U. per lb		12930

To correlate any of the seams exposed on Sharp creek with those observed in the tunnel, or to trace the continuity of seams along the strike of the for-

[1] Non-coking.

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mation, would involve much more time than is available, in one field season. The measures, however, were traced continuously from the head of Sheep creek to and across Picklejar creek into the Highwood River area.[1] Along the strike between the P. Burns property and Picklejar creek good indications of coal can be seen at many points.

A traverse up Picklejar creek across the measures proved the existence of workable seams in that locality. Two seams 10 feet and 7 feet in width respectively were observed. A seam about 50 feet in width is reported on Picklejar creek, but was not seen by the writer.

A sample of coal from the 9-foot seam on the slope north of Pocaterra creek was analysed by the Mines Branch and gave:

Proximate analysis:		
Moisture	%	0·6
Ash	%	6·0
Volatile matter	%	17·1
Fixed carbon (by difference)		76·3
Ultimate analysis:		
Sulphur	%	0·6
Calorific value in B.T.U. per lb		14510

Agglomerates
Coal crushed, pulverulent type

The exposures on Sheep creek offer the best opportunities for mining on a large scale. The structural features, judging from the sections available, are less complex than in other parts of the area. Folding appears to be the main factor involved. The section exposed in the Burns tunnel shows some sharp folds in the Kootenay, and these may involve minor faults, but this can be determined only as development progresses.

The faulting characteristic of the Kootenay which crosses the Highwood area extends into that formation on Picklejar creek and renders the structure there somewhat more complicated. Faulting and intense folding are factors to be considered on the west side of Mist creek and on Storm creek. On Pocaterra creek the outcrop of the Kootenay is greatly restricted by faulting, and the rocks are intensely folded.

There are, without doubt, extensive reserves of high carbon bituminous coal within the area examined, and it is reasonable to expect that with more intense prospecting and as development progresses, more and even better coal seams may be uncovered.

Mining methods adopted in other coal fields of the Rocky mountains will apply in this area and the deposits are so situated that railway communication may be provided with little difficulty.

[1] Geol. Surv., Can., Sum. Rept., 1919, pp. 14 C-20 C.

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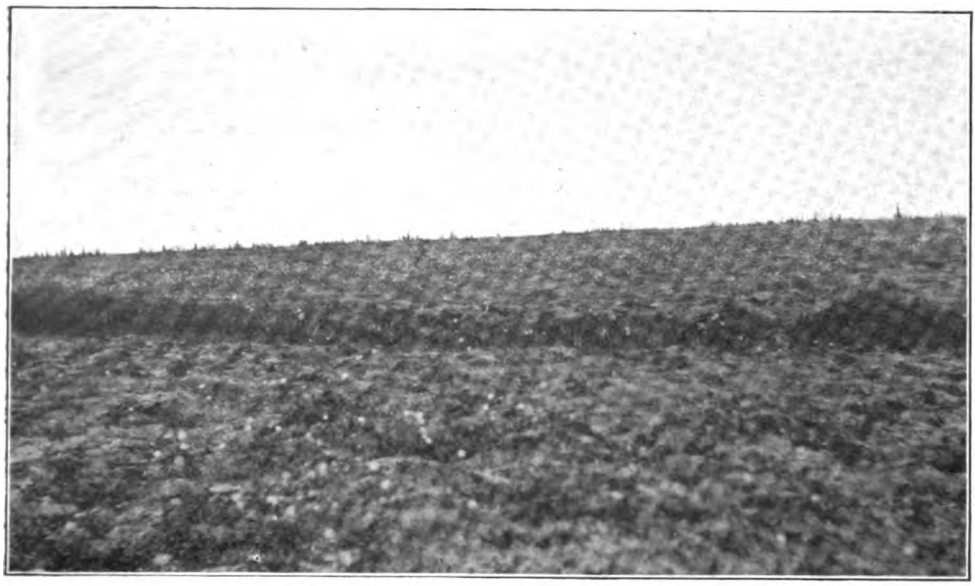
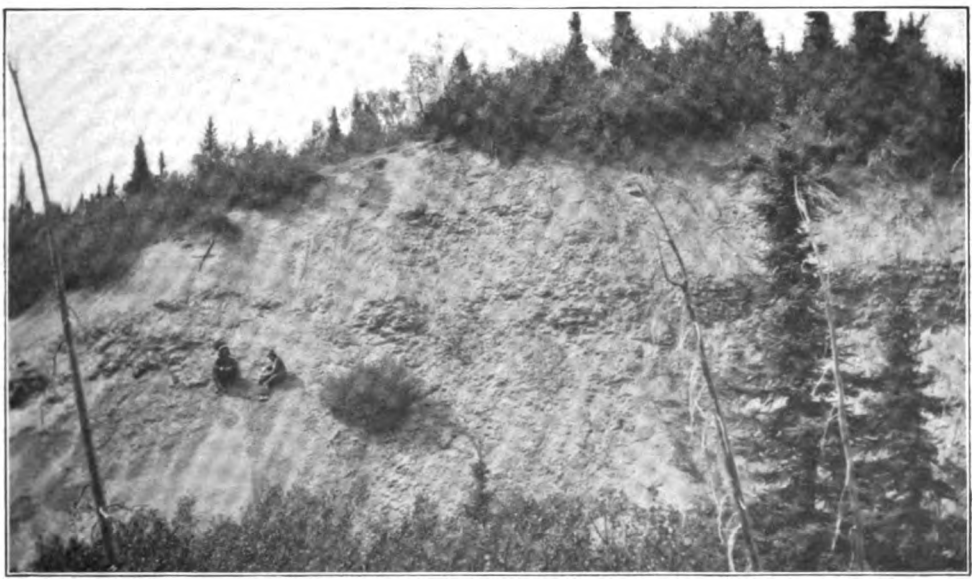


A. Nearly treeless plateau on top of Horn mountains. (Page 47.)



B. Soft crumbling Cretaceous shales. Near head of small creek, southeast end Horn mountains. (Page 54.)

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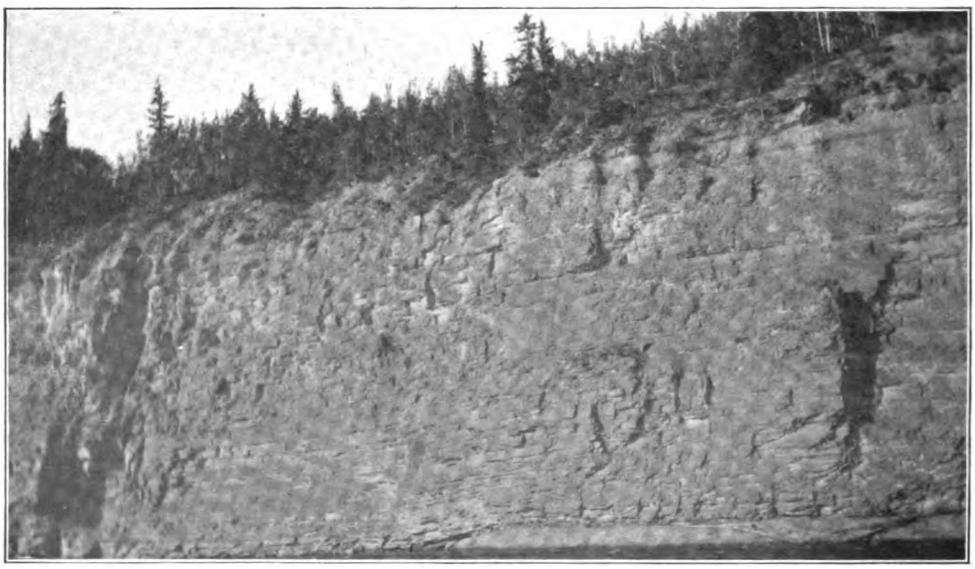
A. Third falls, Trout river. Heavy-bedded limestone of *Cryptonella* zone is shown at the right. (Page 53.)



B. Submarine unconformity between beds of the *Spirifer whitneyi* zone and the *Cryptonella* zone near lower edge of picture. One mile above Third falls, Trout river. (Page 53.)

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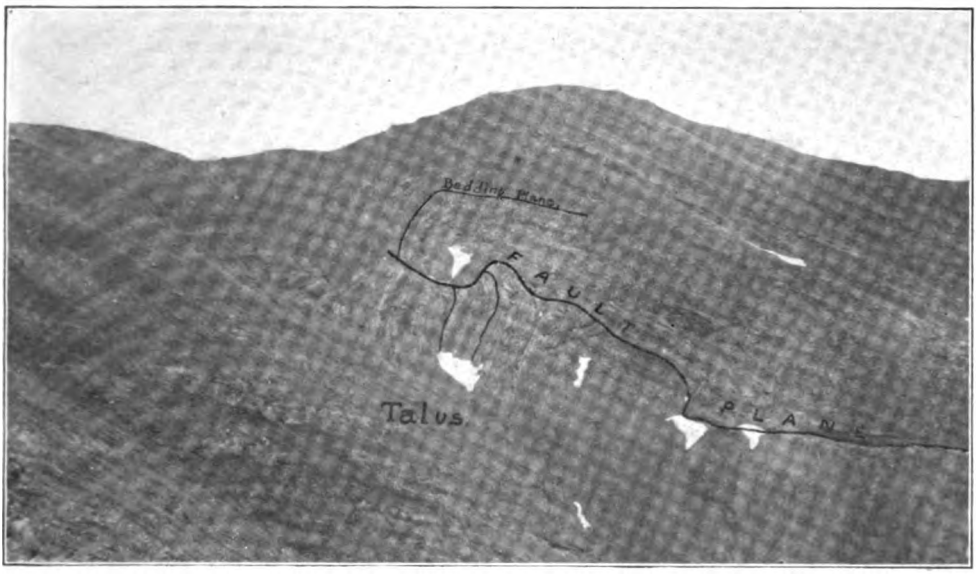
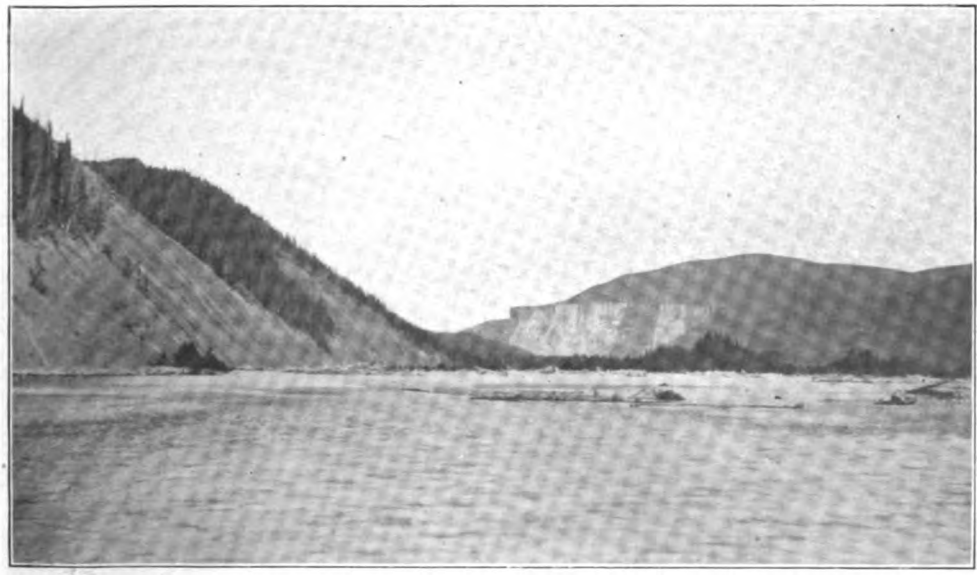


A. Thrust fault of unknown throw exposed on the north slope of Nahanni peak. (Page 70.)



B. Contact between heavy Middle Devonian limestones and Upper Devonian shales about 50 miles up North Nahanni river. The shale in left of picture is the same as the shale which occurs above the limestone cliff on right of picture, the limestone having a dip to the left. (Page 70.)

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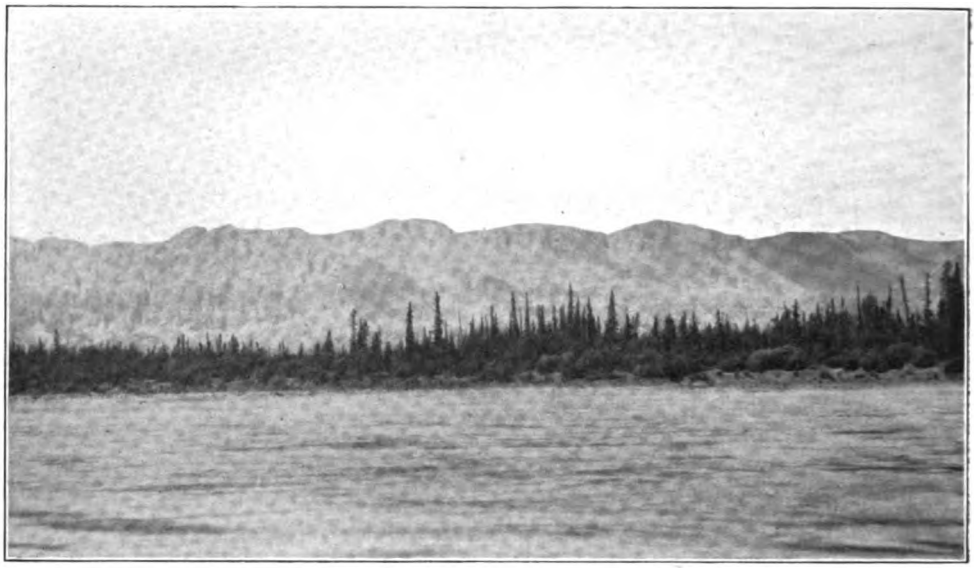
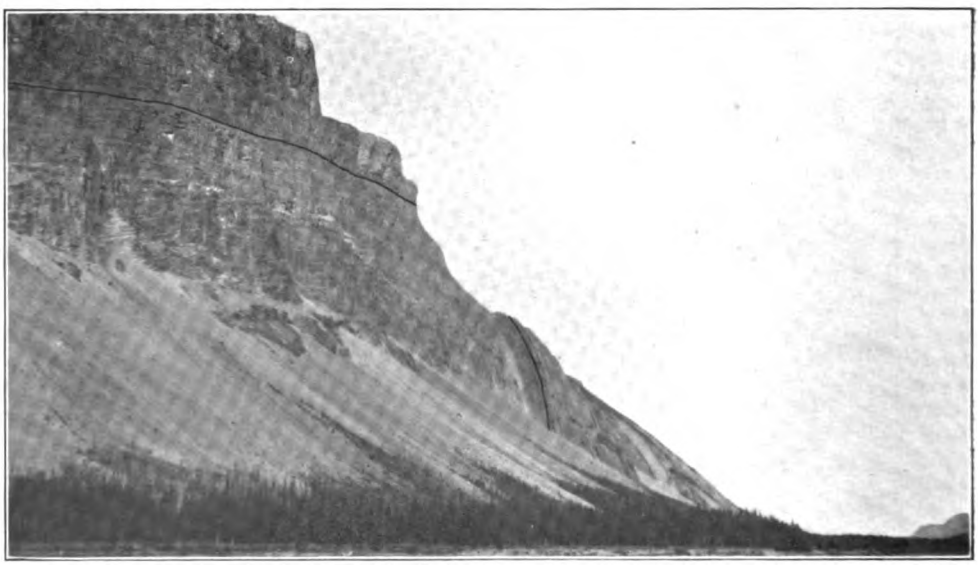


A. Fault line scarp west of Root river. The throw on this fault is between 5,000 and 6,000 feet. (Page 75.)



B. Folded rocks on the west side of North Nahanni river about 40 miles from the Mackenzie. The height to the top of the steeply tilted part is 1,000 feet above the valley bottom. The strata on the top dip away from the face shown in the picture. Faulting has accomplished the folding at various places. (Page 75.)

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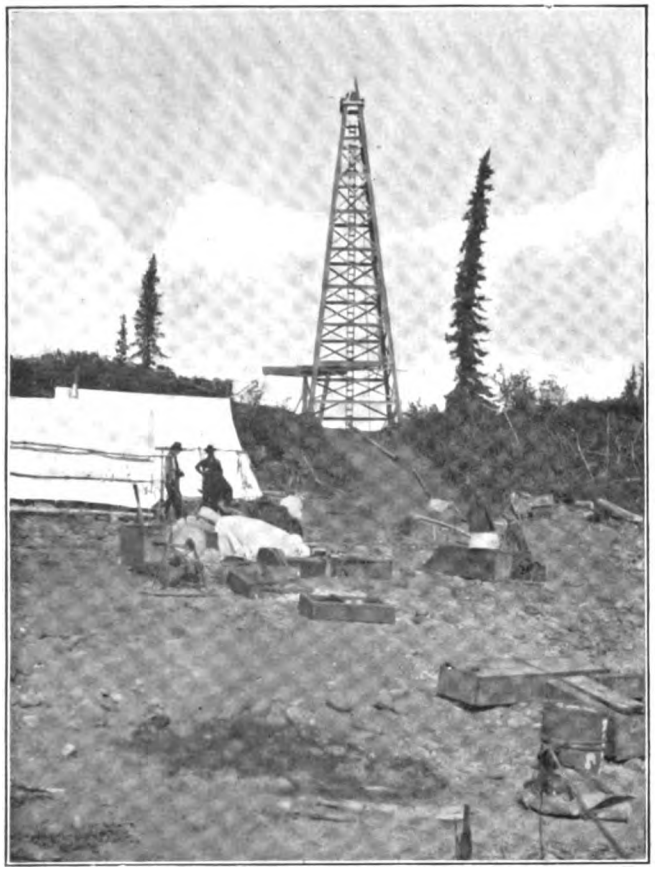
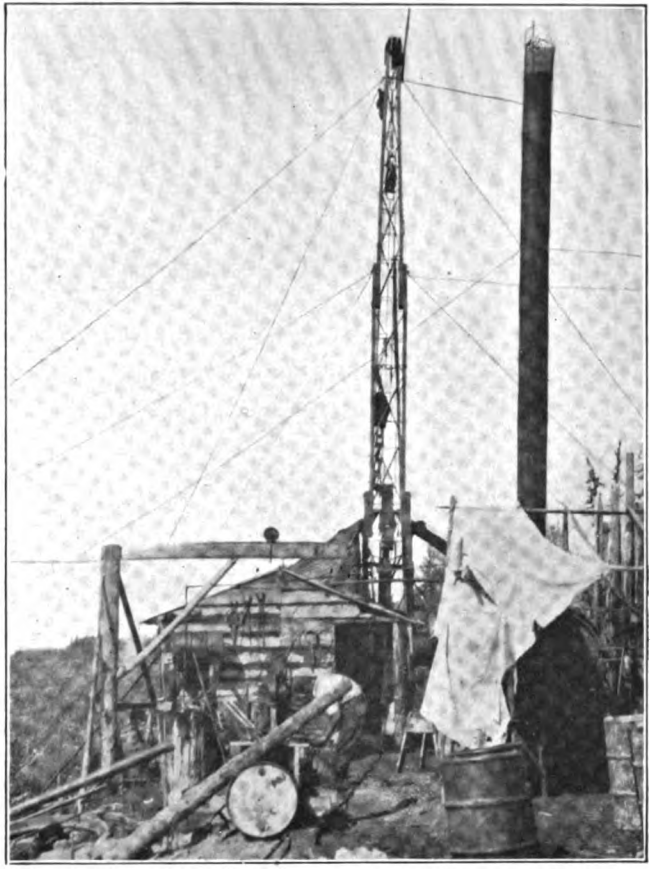


A. Camp and drilling rig of Fort Norman Oil Company under construction, near Norman. (Page 79.)



B. Drilling rig of Imperial Oil Company at Discovery well, Norman. (Page 79.)

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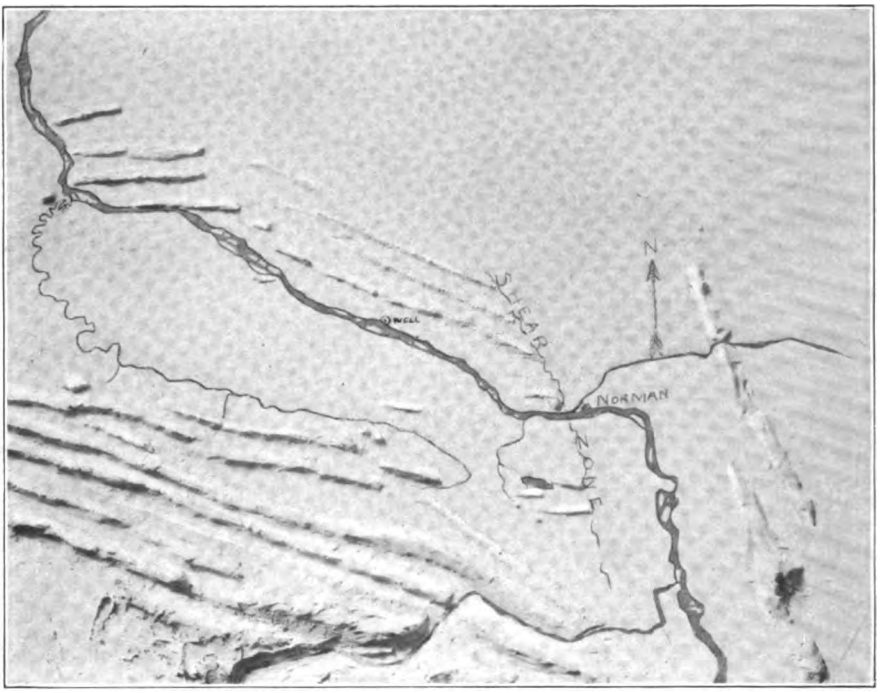
PLATE VI



Relief model showing approximately the positions of the mountain ranges near Norman. (page 90.)

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DEPARTMENT OF MINES
HON. CHARLES STEWART, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

GEOLOGICAL SURVEY
W. H. COLLINS, DIRECTOR.

Summary Report, 1921, Part C

GEOLOGY AND MINERAL RESOURCES OF RICE LAKE AND OISEAU RIVER AREAS, MANITOBA

BY
H. C. COOKE

OTTAWA
F. A. ACLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
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SUMMARY REPORT, 1921, PART C

GEOLOGY AND MINERAL RESOURCES OF RICE LAKE AND OISEAU RIVER AREAS, MANITOBA

By H. C. Cooke

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INTRODUCTION

Rice Lake area of Manitoba has been known for years to contain deposits of native gold, but although many companies of various capitalization have been formed to exploit them, and have advertised the merits of their respective enterprises there are as yet with one small exception no producing mines in the district.

Bodies of copper-nickel ore were found in Oiseau (or Bird) River area in the summer of 1920. Although prospecting could not have been far advanced by the winter of that year, reports as to the immense size and value of the new ore-bodies were already being circulated.

Accordingly, the writer was instructed to examine these two areas in as detailed a manner as time would permit, to obtain first-hand information regarding the size and probable value of the ore-bodies opened up, and, if possible, to determine the origin of the ores, for the future guidance of prospectors and investors.

About a month was spent in the examination of Oiseau River area, and afterwards about six weeks at Rice lake. Leaving Rice Lake area by Wanipigow (or Hole) river, en route to lake Winnipeg, a brief examination was made of the gold deposits at Hay lake and Beaver river. A rapid trip was then made up Maskwa (Bear) river, to compare the nickel deposits there with those at Oiseau river, and also to examine some newly reported discoveries.

The results of the work are set forth fully in this report, which is accompanied by large scale maps of Oiseau River and Rice Lake areas illustrating the salient features of the geology. The mapping, however, is generalized rather than detailed. In Rice Lake area, for example, the part coloured on the map as Keewatin (Rice Lake series or schist-complex) is intersected, in reality, by numerous dykes of later age. No attempt was made to map them, as they are not economically important and the time available for field work was limited. It was possible only to ascertain their character and age relations.

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The writer is indebted to many residents of Winnipeg for information and assistance, and in particular to the owners of the various mineral claims and to the companies which are exploiting the mineral deposits. The writer especially wishes to express obligation to Mr. Gordon MacTavish, of Winnipeg, for useful information and introductions; to the owners and managers of the Devlin, Gold Pan, Pan Extension, and Gabrielle mining companies for aid during the prosecution of the field work; and to Captain Ennis, for valuable assistance in the Wanipigow area.

Location and Means of Access

Oiseau river is a stream 100 to 150 feet wide, with a perceptible current, and a course somewhat south of west. Its mouth lies at the east end of lac du Bonnet, an expansion of Winnipeg river about 25 miles above lake Winnipeg. About 18 miles above lac du Bonnet Oiseau river expands to form Oiseau lake, a beautiful body of water 3 or 4 miles long and 1 mile wide. The nickel discoveries are on the north side of the river, about 3 miles below Oiseau lake, in sections 27 and 35, range 15, township 17.

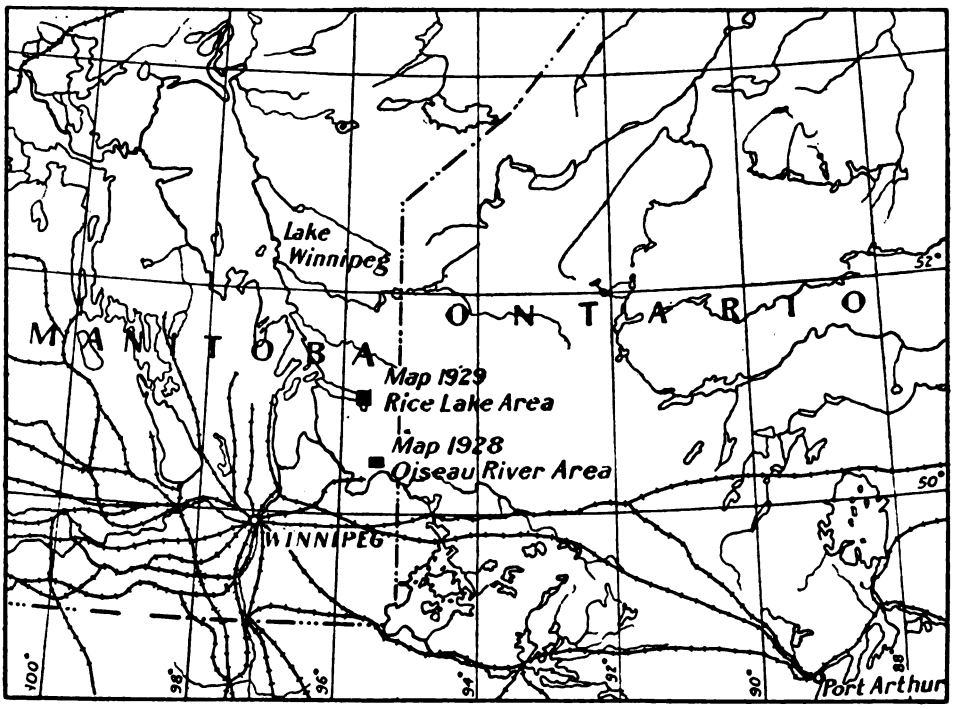

Figure 1. Index map showing the location of Rice Lake and Oiseau River map-areas, Manitoba.

The common method of reaching the district from Winnipeg is by the Canadian Pacific railway to Lac du Bonnet village, a small settlement on Winnipeg river 6 miles above lac du Bonnet. Here gasoline launches may be obtained to cover the 28 miles between the village and the first rapids on Oiseau river. The remainder of the route, up Oiseau river, must be travelled by canoe. The first portage is more than a mile long, but the others, five in number, are all very short; the whole distance between Lac du Bonnet village and the nickel discoveries may be easily covered in a day, travelling light.

Rice Lake district lies only about 35 miles slightly west of north from Oiseau lake, but there is no direct route between the two, and the speediest method of getting

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from one place to the other is via Winnipeg. A train or electric railway runs to Selkirk, and the Northern Fish Company run a steamer as far as Hecla, whence a gasoline launch conveys passengers to the mouth of Manigotagan river, up which the canoe route to Rice lake is 30 miles.

For winter travel a road has been cut from Fort Alexander directly across country to Rice lake.

Previous Work

In 1912 a general survey of the water routes of the whole district was made by E. S. Moore, for the Geological Survey, together with a hasty examination of the shore geology. Wanipigow, Manigotagan, and Oiseau rivers were surveyed.[1] In 1916 a brief examination of the Rice Lake gold discoveries was made by J. A. Dresser and John Marshall, for the Geological Survey,[2] and in 1920 J. S. DeLury, for the Manitoban government, made a fairly thorough examination of the same area, and published a detailed account of the gold occurrences.[3] In the autumn of 1920 W. S. McCann, for the Geological Survey, examined the nickel discoveries up the Maskwa and his report[4] contained a map showing the outlines of the nickel-bearing intrusive, and the location of the principal discoveries.

GENERAL GEOLOGY

General Statement

The following geological column for the district was established by E. S. Moore:

Precambrian		Granite and gneiss
		Intrusive contact
	Wanipigow series	Conglomerate, arkose, greywacke, etc.
		Probable unconformity
	Keewatin — Rice Lake series	Lavas and their schists

Moore's results, good as they were, were limited by the hasty nature of his exploratory work, which confined him to the shore-lines. Had time permitted him to extend his work inland, other outcrops would have been discovered that would undoubtedly have altered his conclusions on the stratigraphy. Later workers, such as Dresser, Marshall, DeLury, and McCann confined their attention to the mineral discoveries, and accepted Moore's conclusions as to the geology without much question.

The writer's methods of work were the antithesis of Moore's, in that detailed examinations were made of small areas, which, moreover, were particularly suitable for such examination by reason of their complex geology and excellent rock exposures. In this way evidence was obtained that determines more completely the Precambrian history of the region and adds somewhat to Moore's geological column. The principal points of difference between Moore's conclusions and those of the writer may be briefly stated as follows:

In his map of 1912 Moore shows two bands of the Wanipigow series of sediments, a broad one extending from Wanipigow (Hole) lake through Rice lake, then southeasterly to the headwaters of Manigotagan river, the other extending through Oiseau River area. Marshall later showed that the mapping of the former band was incorrect and that a granite mass around Long lake divides the band into an eastern part and a western part. The writer was unable to examine the eastern area around the headwaters of Manigotagan river, but did study the other occurrences around Rice and Oiseau lakes; and was able to prove that the supposed sediments in both places are really bedded tuffs in large part, and that they rest with perfect conformity on the surface of the lava flows composing Moore's Rice Lake series. Moore's Rice Lake and

[1] Moore, E. S., Geol. Surv., Can., Sum. Rept., 1912, pp. 262-270.
[2] Dresser, J. A., Geol. Surv., Can., Sum. Rept., 1916, p. 169.
[3] DeLury, J. S., "Mineral Prospects in Southeastern Manitoba." Manitoba Bulletins.
[4] McCann, W. S., Geol. Surv., Can., Sum. Rept., 1921, pt. C., p. 19.

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Wanipigow series, therefore, become, respectively, the volcanic and sedimentary members of a single series of surficial rocks. In subsequent parts of this report the name Wanipigow series will, therefore, be omitted, and the whole body of volcanics and sediments will be called the Rice Lake series.

The volcanics and sediments are intruded by granites. Moore mentions only one period of granitic intrusion, but the evidence obtained during the past summer proves that there were really two such periods. The two granites will hereafter be referred to as to the "earlier granite" and the "later granite." Between the intrusion of these two granites there intervened a very long period of time, during which great deformation of the region took place, together with intrusion of a variety of basic igneous rocks. The most important and probably the latest of these was a gabbro which formed sills and laccoliths of varying size. Apparently it preceded by a very short interval the intrusion of the later granite.

The geological column established by the writer's work is, therefore, as follows:

Table of Formations

Precambrian			Later granite
			Gabbro.
			Relations unknown
			Diabase dykes
			Feldspar porphyry
			Relations unknown
			Hornblende porphyry
			Earlier granite
	Keewatin?	Rice Lake series	Tufaceous sediments
			Confortable contact
			Lavas and breccias

Rice Lake Series

PETROGRAPHY OF VOLCANIC PORTION

Basalt

The volcanic portion of the Rice Lake series is made up of lavas of varying composition. In Oiseau River area most of the lavas are massive, rather fresh-looking basalts, in flows that vary from a few feet to more than 100 feet in thickness. Pillow structures were observed in a few places, but were rare, and flow textures were not seen. The grain varies from fine, almost glassy, at the upper edges of the flows, to a maximum of perhaps 1 mm. in their lower parts. The coarser-grained parts of the basalt flows so strongly resemble some of the finer-grained phases of the nickel-bearing gabbro that the two are frequently confounded. The basalt, however, maintains its fine grain over distances of hundreds of feet, whereas the grain of the gabbro is fine only near a contact, and increases rapidly with distance from the contact, becoming much coarser than any part of the basalt.

Only one specimen of basalt was examined microscopically. It is a somewhat porphyritic rock, in which phenocrysts of biotite, partly chloritized hornblende, and andesine form 30 per cent to 40 per cent of the mass. The phenocrysts average 0·3 mm. in diameter. They are embedded in a matrix of 0·01 to 0·02 mm. grain, made up of about 30 per cent of pale green actinolite in small needles, and 70 per cent of fine-grained feldspar, probably andesine. There is no evidence that the hornblende present is secondary after augite, unless the whole rock has suffered recrystallization. The lava seems, therefore, to be an andesite rather than a basalt.

Dacite

In Oiseau River area there also occurs, in section 29, a black, fresh-looking lava, composed of numerous good-sized phenocrysts of white feldspar embedded in a fine-grained black matrix. Under the microscope the rock is seen to be partly granulated and altered. The phenocrysts, of all sizes up to 1·5 mm. in diameter, include

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both quartz and andesine feldspar. They are badly granulated, and the feldspar largely altered to sericite or paragonite. There is a good deal of an incompletely chloritized mineral present, that may have been biotite. The groundmass is somewhat altered and hardly distinguishable from the granulated parts of the phenocrysts. It appears to have been composed mainly of feldspar. The lava, therefore, might be termed an altered dacite.

Andesite

Basalt, with good pillow structures, occurs on the north shore of Rice lake, but the main body of the volcanic rocks in the area consists of porphyritic andesites. Phenocrysts of andesine feldspar up to 3 mm. in length form perhaps 25 per cent of the bulk of this rock. The matrix, of about 0·03 mm. average grain, is composed of similar feldspar and needles of chlorite probably secondary after actinolite. A good deal of calcite, epidote, and sericite is present. In some of the fresher hand specimens the matrix appears glassy and almost black, but more commonly it has a greyish green tinge, due to the presence of alteration products.

Breccias, extremely common around Rice lake, include both flow and tuff breccias, but are mainly flow breccias that grade into massive lava by decrease in the number of fragments.

Rhyolite

Rhyolite, also, occurs at the northeastern end of Rice lake, on the Rachel claim, L. 47-124. The rock is very light grey and fine grained. It is slightly porphyritic, containing a few phenocrysts of quartz and oligoclase feldspar up to 0·5 mm. diameter. The matrix, with an average grain of 0·05 mm., consists mainly of oligoclase feldspar with 2 or 3 per cent of quartz and about 20 per cent of chlorite needles. The form of the chlorite suggests that it is secondary after actinolite. The minerals have been more or less granulated, presumably by the strains of folding.

PETROGRAPHY OF SEDIMENTARY MEMBER

The sedimentary member of the Rice Lake series includes those rocks formerly known under the name of the Wanipigow series.

Cherty Tuff

In Oiseau River area the basal beds are thin-bedded cherts, composed of fine-grained volcanic ash more or less converted to silica and albite feldspar by the action of solutions accompanying or following the volcanic outbursts. The chert beds are interstratified with coarser-grained, thicker beds of relatively pure ash. The ash beds grade upward into the prevailing rock of the series, a sandy greywacke or impure quartzite with occasional slate beds.

Conglomeratic Tuff

In section 31 there is a wide belt of interbedded greywacke and coarse tuff. The tuff contains numerous rounded pebbles of basalt, and thus strongly resembles a conglomerate. The resemblance is heightened by the fact that different varieties of rock appear to be represented in the pebbles; but close examination proves that the apparent differences are due to the varying textures of the basalts that supplied the pebbles. The rock is, therefore, an intraformational conglomerate, the materials of which were probably derived from adjacent rocks by rapid erosion, and deposited in a local basin. Such a conglomerate does not imply the existence of any great time interval between its formation and that of the underlying lavas.

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Rhyolite Tuff

In Rice Lake area the basal sediments again consist of a very fine-grained chert, or cherty tuff, that rests directly on the glassy surface of the rhyolite previously described (page 5) and is composed of numerous fragments of quartz and sodic feldspar, up to 0·15 mm. diameter, embedded in a very fine-grained, highly sericitic groundmass. The sericite is probably secondary, formed under the pressures that folded the rocks.

This tuff is overlain on the south side by a bed of coarse rhyolite tuff some hundreds of feet in thickness, made up of sharp-angled fragments of rhyolite averaging about an inch in diameter, in a finer-grained matrix of the same material.

Grit

It is overlain in turn by a well-bedded grit, composed of sharp-angled fragments of quartz, feldspar, and rhyolite, and is well exposed on the southeast corner of the large island in Rice lake. This, again, is overlain by the normal sedimentary rock of the region, a massive quartzite more or less converted to sericite schist over considerable areas.

Quartzite

The bedding of the quartzite is commonly so thick, and the character of the material so uniform, that observations on the strike and dip of the beds are difficult to obtain. In places, however, the normal quartzite grades into finer-grained, muddier material in the upper parts of a bed, and this in turn is overlain by the coarser-grained quartzite of the succeeding bed.

The quartzite is a grey rock with an average grain of 0·5 mm. Grains of this size compose about 60 per cent of the rock, and are mostly of quartz, with a few of oligoclase feldspar. They are to some extent granulated and drawn out into "eye" shapes. The remaining 40 per cent of the rock is mainly very fine-grained quartz and muscovite or paragonite, the last probably formed by the metamorphism of the feldspar constituent.

STRUCTURAL RELATIONS

Stratigraphy

The work of the past summer was not sufficient to show whether the sedimentary part of the Rice Lake series overlies all the lava flows composing the volcanic member, or is interstratified between them. In Oiseau River area the sediments overlie the lavas, but their upper side was not seen. In Rice Lake area they appear to be both underlain and overlain by lavas, but strike faults are so numerous that the apparent structure may be due to repetition of beds from this cause, although no direct evidence of faulting along contacts could be observed.

In Oiseau River area the relations between the lavas and sediments were established as follows: In many places a careful examination discovered the lines of contact of two lava flows. At such places a relatively coarse-grained variety of basalt, the slowly cooled bottom of a flow, is in sharp contact with a very fine-grained, almost glassy basalt representing the rapidly cooled surface of an earlier lava flow. From such contacts the strike and dip of the lavas can be determined. All the determinations thus made give the lavas approximately east-west strikes and vertical dips, and the glassy phases, the original surfaces, invariably form the south part of the now vertical flows. Since the south side of the flows is, therefore, the upper, it follows that any given bed or flow is younger than beds or flows to the north of it, and older than beds or flows to the south of it.

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In one place, along the line between sections 27 and 28, good pillow structure is developed in the basalts. Pillow structure is believed to be most commonly developed in lavas when they are extruded under water, and when the flows are fairly thick the structure does not extend through the whole mass of lava, but affects only the parts near the surface. In such circumstances it can be used to determine structure, as the pillowed parts of a flow will be the upper side. A careful examination of the structure in Oiseau River area confirmed the conclusions drawn from other data, that the folded lavas have a general east-west strike, a vertical dip, and face southward.

Since the lavas of the volcanic series face south, and the sediments are found south of the lavas, the sediments must overlie the lavas.

This determination does not settle the question, however, as to whether the sediments overlie the lavas conformably or unconformably. Very careful search was, therefore, made for actual contacts of the two series, and such contacts were found in several places in sections 29 and 31. In each case the contact is between sediments and the glassy upper parts of lava flows, never between sediments and coarse-grained basalts; indicating that the sediments were laid down directly on the surfaces of lava flows, before erosion had the opportunity to wear away the flows or cut channels into them. The sediments are never conglomerates at the contacts, but are either cherts or slates, neither of which is a product of the erosion of the underlying lavas. Evidently, therefore, there was no interval of erosion between the deposition of the basalts and that of the overlying sediments. In addition, no folding took place between the formation of the two, for the strike and dip of the sedimentary beds are the same as that of the lava flows. The two formations are, therefore, perfectly conformable.

The conformability of the sediments and lavas is further seen in lot 31. Here the contact of the two formations is not a sharp line, but a broad band in which flows of lava alternate with varying thicknesses of sediments. On the map, north of the main body of sediments in section 30, there is shown a single wide band of lavas, followed by a band of sediments, which is succeeded again by lavas. The mapping does not fully represent the true state of affairs. In reality there are numerous narrower alternating bands of sediments and lavas, particularly in the lava band mapped to the south of the norite band, and in the northern part of the succeeding band of sediments. The mapping here merely expresses which material, lava or sediment, was predominant.

Evidently, therefore, sedimentary deposition began as the period of lava extrusion drew to a close, but sedimentation was locally interrupted from time to time by the extrusion of more lavas. Such facts emphasize the lack of any time break between the deposition of the two formations.

In Rice Lake area the sediments form a band that runs through the lake in a general east-west direction, and lavas are found both north and south of this band. Moore assumed that the sediments form a syncline, and that the lavas dip beneath them both on the north and south. However, examination of the lavas by the methods described shows that they have a similar strike and face toward the south on *both* sides of the sediments. The band of sediments is, therefore, either overlain as well as underlain by lavas, or else the lavas to the south have been faulted into their present position. Although no direct evidence of such faulting was obtained, the possibility cannot be altogether dismissed, since the southern contact of the sediments and lavas is hidden by drift, and faults parallel to the strike of the contact are common in the area.

The sedimentary beds at Rice lake have already been shown to consist on the north side of fine-grained cherty tuff in direct contact with glassy rhyolite; the cherty tuff is succeeded on the south by coarse rhyolite tuff, finer tuffaceous grit, and then by quartzite. All of these members are interbedded with each other at their contacts, indicating a smooth and continuous sequence of deposition between the rhyolite and the quartzite; hence as the south side of the rhyolite is the upper, the sediment must overlie it with perfect conformity.

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To sum up: the sediments around Rice lake overlie a part of the volcanic rocks conformably; they are overlain in turn by more lavas, unless there is a strike fault at their southern contact which brings the underlying volcanics into apparent stratigraphic superposition over the sediments.

Folding

The Rice Lake series has been closely folded, and the strata thrown into approximately vertical attitudes, or locally overturned. The areas examined are not large enough to contain whole folds, from a study of which axial directions might be determined, so that only a simple statement of observed dips and strikes can be made. In Oiseau (Bird) River area the sediments and lavas strike uniformly north 70 degrees west, except where drag folding has caused local variations. The dips are all vertical or nearly so. The beds all face the south, thus forming the north limb of a syncline whose axis lies to the south of the area studied. The corresponding anticline to the north has been destroyed by the intrusion of the earlier granite. In Rice Lake area the strike of the sediments and lavas varies from about north 75 degrees west north of the Rice to about north 50 degrees west in the southern part of the area. The southwest side of the beds and flows is the upper side, so that they also form parts of the north limb of a syncline. The dips are mostly nearly vertical, but around Rice and Red Rice lakes there has been strong overfolding, giving the strata reversed dips toward the north. The overthrust was so severe that near the southern contact of sediments and lavas the overturned strata dip as low as 30 degrees north. The southern limb of this overturned syncline is cut off by the intrusion of the later granite, and the earlier granite has obliterated the anticline to the north.

The folding described did not all take place at one time. There is good evidence that there were two periods of folding, corresponding roughly to the times of intrusion of the earlier and later granites. This question is considered more fully in a subsequent part of the report. The pressure causing the folding is supposed to have come from the northeast, as faulting was due to thrust from that direction.

Faulting

The Rice Lake series, together with the earlier granite, has been greatly broken up by large faults in both the areas examined. The faults are important from an economic point of view, in that they controlled the intrusion of the gabbro magma in Oiseau River area, and the formation of the gold-bearing veins in Rice Lake area.

In Oiseau River area the peculiar shape of the northern contact of the gabbro mass attracted the attention of the writer. Although the gabbro forms a sill-like mass, intruded parallel to the east-west strike of the sediments and lavas, its northern contact is repeatedly stepped due north for greater or less distances. The line of these north-south sections of the contact is generally a narrow valley or depression.

Some of these narrow valleys were followed northward beyond the turning point of the contact, until outcrops in the granite were obtained, and in each case zones of strong shearing were found in the bottom of the valley. The shearing is such as to convert the otherwise massive granite into highly fissile sericite schist over various widths. Evidently the granite has been faulted, probably with great displacement, along these lines of shear.

Faulting must have preceded the gabbro intrusion since the southern boundary of the sill is not displaced by the faults, but runs along in a smooth, gently curving line, and the faults merely had the effect of localizing the intrusion. This question will be fully discussed, however, in the description of the bodies of gabbro.

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The only fault in Oiseau River area whose direction of displacement can be determined occurs in the western part of sections 29 and 32. This fault shows an horizontal displacement of approximately 1,500 feet, the east side having moved toward the south. It thus resembles the faults of Rice Lake area. The faults of Oiseau River area differ from those of Rice Lake area in having a somewhat more northerly trend.

As the faults of Oiseau River area have no known economic significance other than their effect in controlling the intrusion of the gabbro, they were not traced for any great distance. In Rice Lake district, however, the faults have been the fissures in which the gold ores were later deposited, and on this account the larger ones were traced as far as possible. The faults so traced are shown on the accompanying map No. 1929. There are also smaller unmapped faults very difficult to trace, because, though in the softer rocks they may form well-defined shear zones, in the harder rocks they are apt to pass into vaguely defined zones of fracture. Moreover, they are so numerous that it is impossible to project one of them through even a small drift-covered area without being in doubt as to whether a fault is, on the far side of the interval, the fault previously traced, or a neighbouring one.

The faults vary considerably in direction, as the map shows, but are in general north 60 degrees west, north 30 degrees west, and north 10 degrees west. Those with a strike of about north 60 degrees west may be termed strike faults, as they either parallel or cut at a small angle the strike of the lavas and sediments. The others cut the bedding of the sediments and lavas.

Small strike faults with almost vertical shear planes are very common throughout the area. The planes of the larger strike faults, particularly the large shear zone on the south of Rice lake, and that northeast of Red Rice lake, dip to the north at varying angles, sometimes steeply, sometimes flatly. The direction of the shear planes together with other data, indicate that they have been formed by overthrusts from the north or northeast.

The other classes of faults have shear planes either vertical or dipping 70 degrees to 80 degrees toward the east. They exhibit a uniform direction of movement; the eastern side has always moved toward the south, relative to the western side. The movement has been almost an horizontal one, with a slight tendency to the scissors type. At the northern end of the faults the east side has been forced upward as well as southward; near the centre of the area the movement is practically horizontal; whereas at the south ends of the faults there has been a slight but distinct downward movement on the east side, in addition to the lateral movement.

As the map shows, the faults with the more northerly strikes turn at their northern ends so as to become the strike faults; there is, therefore, no real reason for separating the different classes. Distinction has been made principally because of the differences in the character of the faults, displayed in their different courses. Faulting has cut the area up into a series of fault blocks. The thrust from the north or northeast has tended to raise each block above, and thrust it over, the adjoining block to the southwest.

Along the lines of faulting the rocks have been transformed into belts of schist of varying width. The softer varieties, more incompetent to resist the shearing stresses, have been converted into fissile schists, as much as 60 or 70 feet in width. Smaller faults yield narrower belts of schist, a few inches or feet in width.

In harder rocks the effect of faulting is much less striking. The larger shear zones narrow to 2 or 3 feet in places, but the smaller ones pass into vaguely defined zones of fracturing. The wider belts of schist reappear where the fault re-enters softer rock, after passing through the belt of harder rock. The shear zones thus resemble a series of lenses placed end to end, rather than a ribbon-like band of uniform width. The lenticular structure is accentuated by certain other factors, so that it appears even where the rocks cut by a fault are all much the same.

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When the pressures causing the faulting first began to act, rather crooked fractures were produced (Figure 2) presumably because there were joints or other pre-existing lines of weakness in the rocks, and fracture followed these lines of weakness. Later thrusts caused horizontal movement along the fault planes, as already

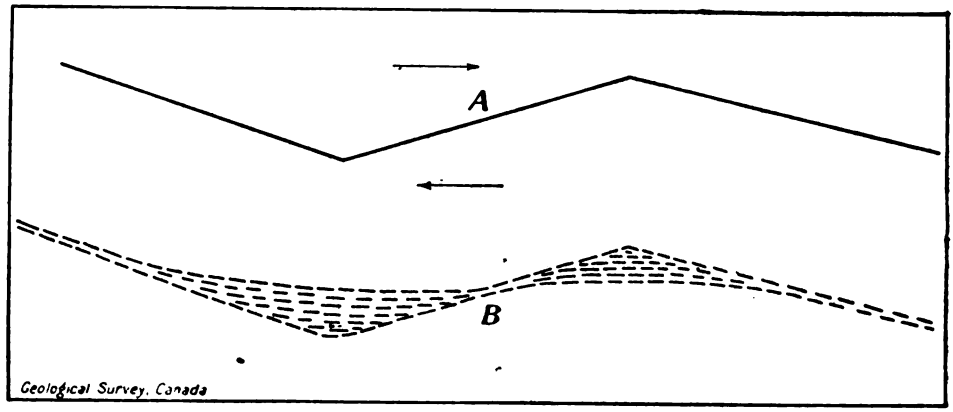

Figure 2. Diagram showing formation of lenticular sheared zone by lateral displacement along a crooked fault.

described, and straightened the bends by cutting off the corners (Figure 2). Thus the bends are now wide zones of sheared rock, and, between bends, the shear zones are much narrower. On the Bluebell property, L. 9-174, from this cause alone the shear zone varies from 33 feet in width to 2 feet within a distance of 150 feet along the strike.

Lateral movement along the fault planes has in places caught up parts of soft beds, to form drag folds within the sheared zone (Figure 3). The formation of such a drag fold, in trebling the thickness of the sedimentary bed, has been accompanied by widening of the sheared zone, seemingly by pushing out its walls. This was observed only in one or two places.

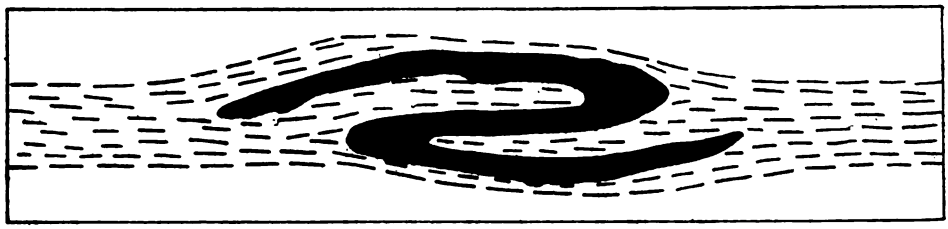

Figure 3. Diagram showing how an included bed (in solid black), drag-folded, may widen a sheared zone (in broken line).

A third cause of change in width is the splitting of the shear zone. A shear zone frequently splits into two belts which, in some cases, reunite around a horse or body of unsheared rock. In other instances the two sheared belts remain apart. Several cases of such splitting on a large scale are shown on the map; the combined zone of shear is larger than either of the two zones into which it splits.

Zones of sheared material are commonly replaced partly or completely by intrusions of igneous rock. Fault zones are easily intruded by igneous magmas, and many dykes on encountering such zones have found it easier to follow than to cross them. In many instances the dyke material now occupies the whole width of the sheared

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zone, in others only a part, thus diminishing or entirely replacing the sheared material.

Time of Faulting

The faults cut the folded rocks of the Rice Lake series, hence are of later date than the folding. The faults have cut the earlier granite, and made wide, sheared zones in it; therefore they are later than the intrusion and consolidation of the granite. The various dykes of the Rice Lake area cut into and across the shearing planes of the faulted zones; hence much of the faulting preceded the intrusion of the dykes. However, the dykes themselves are in cases badly fractured or slightly sheared where they lie within the fault zones, and may be displaced a few feet laterally where they cross a sheared zone, so that although the main faulting took place before the intrusion of the dykes, there was some later movement along the same planes of weakness. The faults do not greatly displace or fracture the later granite and this second period of movement must have occurred between the intrusion of the latest or diabase dykes, and that of the later granite. The later granite is, however, greatly jointed parallel to the earlier set of faults, and small movements, of an inch or a few inches, have occurred along the joint planes; evidently, after the intrusion of the later granite, another small movement occurred, jointing and slightly faulting it.

Faulting thus occurred at three different periods; the first and most intense, after the intrusion of the earlier granite but before the intrusion of the various dykes; the second, less severe, after the intrusion of the dykes but before the intrusion of the later granite; the third, comparatively slight, after the intrusion of the later granite.

Time of Folding

It has been shown that a folding movement occurred prior to the faulting of the Rice Lake series. Although it is not known precisely whether this folding took place before or after the intrusion of the earlier granite, it is inferred to have taken place before intrusion. The massive granite in places contains schistose blocks of the Rice Lake series, in which schistosity must have been developed before they were broken off by the intruding magma. Folding and mountain building are, moreover, usually accompanied or closely followed by granitic intrusion, and granitic intrusion is not known to precede folding.

In Oiseau (Bird) River area the nickel-bearing gabbros cut across the faults in the earlier granite and Rice Lake series without being themselves displaced, and the sills are tilted up on edge. Thus the sills, which are younger than the faults, have also suffered folding. There must, therefore, have been a second folding movement quite late in the history of the region, later than the earlier granite, later than the faults that cut it, and later than the intrusion of the gabbro. Since batholithic intrusion often follows folding, it may be inferred that the later folding just preceded the intrusion of the later granite.

There appear, therefore, to have been at least two periods of folding in the Precambrian of eastern Manitoba, the first preceding or accompanying the intrusion of the earlier granite, the second with similar relations to the later granite.

Relations of Rice Lake Series to Younger Formations

The Rice Lake series is the oldest formation in either of the districts examined, so that all its external relationships are to younger rocks, all of which are igneous and intrusive. The facts of intrusion were established in each instance by the usual methods; the intrusive was observed to cut across the bedding of the Rice Lake series, to have chilled edges at contacts, and to contain inclusions of the older rocks.

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EARLIER GRANITE

The earlier granite is found on the north side of the band of Rice Lake series that extends from Rice lake to the mouth of Wanipigow (Hole) river (See Map No. 1285 by E. S. Moore, 1912). It extends north of Wanipigow river for a considerable distance at least, for the writer went north 6 miles from Wanipigow (Hole) lake without encountering any other rock. The earlier granite is also found on the north side of the band of Rice Lake series in Oiseau River area. Its width here also is unknown, though it must be less than 12 miles, since later granite is found around the Maskwa River nickel deposits.

Methods of Distinguishing the Earlier and Later Granites

It is impossible to distinguish the earlier granite from the later granite by petrographic means, either in hand specimens or thin sections. The writer searched with the utmost care for some petrographic characteristic that might be used to distinguish the two, but without success. There is no single characteristic of composition, texture, or alteration in either granite that may not be matched in specimens from the other.

It is true that a larger proportion of the earlier granite than of the later appears to have suffered alteration by weathering. Perhaps half the rock specimens collected from a body of earlier granite will contain dull-looking, altered feldspars, and partly chloritized ferromagnesian constituents, whereas such a specimen from the later granite is rare except from the actual surface. On the contrary, feldspars in the later granite are fresh and glassy, and its ferromagnesian minerals without a trace of alteration. However, in places perfectly fresh and unaltered specimens may be collected from the earlier granite, so that it would be extremely unsatisfactory to endeavour to distinguish between the two by such means. Other and better criteria are available, and it is better to rely on them entirely.

It has been pointed out that the earlier granite is cut by the faults of the region, but that the later granite is not. Accordingly there are wide shear zones in the earlier granite, along which it has been converted into a highly fissile schist. Shear zones of this sort are very prominent in the granite north of Wanipigow river and lake, and common, though less prominent, in the granite of Oiseau river. No such feature is to be found in the later granite, in which the most pronounced deformation is jointing, with lateral movement of a few inches at most along the joint planes.

The earlier granite is cut by basic dykes. In the area north of Wanipigow river the dykes are of diabase, in Oiseau River area of gabbro. In both places dykes are fairly numerous. The later granite, apparently, is not cut by dykes of any kind, except those of pegmatite. On the contrary, it cuts across the diabase dykes in Rice Lake area, and the gabbro in Maskwa River area.

Petrography

The earlier granite is a coarse-grained, grey, greenish grey, or reddish rock, usually equigranular, but in places containing porphyritic feldspars. It varies a good deal from place to place, both in composition and degree of alteration. In Oiseau River area it is a very fresh, reddish rock with a porphyritic tendency, and an average grain of 2 to 3 mm. The specimen examined microscopically is composed of nearly 50 per cent quartz, 2 or 3 per cent of biotite, 35 per cent microcline, and 10 per cent of albite, with a few crystals of orthoclase. The albite has been somewhat altered to sericite or paragonite, but the other feldspars are almost unaltered.

The earlier granite north of Wanipigow river is much more largely altered, and characterized by the greenish tints due to the presence of alteration products. When fresh, it is a grey or white rock, with an average grain of 1 to 2 mm. The composition averages about 30 per cent quartz, 10 per cent to 15 per cent of ferromagnesian mineral, mostly common green hornblende with a little biotite, the remainder a feldspar, all of whose optical characters are those of andesine Ab_{60} An_{40} except the

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refringence, which is a little low. It is probable, therefore, that some orthoclase is dissolved in the andesine and reduces its refringence. The composition of the Wanipigow River granite indicates it to be a granodiorite rather than a true granite. Altered phases show alteration of the feldspar to sericite or paragonite and epidote, and of the hornblende to chlorite.

Structural Relations

The earlier granite is intrusive into the Rice Lake series. The mapping shows the granite cutting across the bedding of the Rice Lake series, in some places completely through the older volcanic rocks and up into the younger sediments. The usual swarm of stoped-off fragments is found in the granite near contacts. Dykes from the granite penetrate the Rice Lake series for greater or less distances from contacts.

The earlier granite has suffered from the faulting of the region and presumably also from the later period of folding although no especial folding effects were obtained. The faulting has produced zones of schist up to 100 feet in width. In the area north of Wanipigow river and lake the faults with a general east and west strike have made broad zones of schist, whereas those with northerly strikes have formed very much narrower zones, rarely exceeding 3 or 4 feet in width. The later folding, due to stresses from the north, may have made use of the east-west planes of weakness established by the faulting as slipping planes, along which movements relieving the stresses from the north, may have made use of the east-west planes of weakness

The earlier granite is cut by the various later intrusives of the region. No feldspar porphyry dykes were observed in it, but the diabase dykes of Rice Lake district, and the gabbro dykes and sills of Oiseau River district both intrude it. No contact of the earlier and later granite was seen, although there must be such a contact between the Oiseau River and Maskwa River areas.

The earlier granite was thus intruded prior to the intrusion of the various basic igneous rocks of the region, prior to the faulting and subsequent to the deposition of the Rice Lake series. It probably accompanied or closely followed the folding of the Rice Lake series.

HORNBLENDE PORPHYRY

A few dykes of hornblende porphyry were found in Rice Lake district, cutting the bedding of the series or intruded parallel to it. The porphyry is a hard, fresh rock, composed of needle-like phenocrysts of hornblende up to half an inch in length embedded in a fine-grained grey matrix. Its external relations are not known, as it was not found in contact with any of the rocks of the region, with the exception of the lavas of the Rice Lake series.

FELDSPAR PORPHYRY

Dykes of feldspar porphyry are numerous in Rice Lake district. Singularly enough, they were observed to cut only the volcanic rocks of the Rice Lake series, although the facts at hand indicate that they are later, not only than the Rice Lake series as a whole, but also than the earlier granite. They were not seen in Oiseau River area.

Petrographically, the feldspar porphyry is a light grey rock, fresh, hard, and massive, made up of squarish crystals of feldspar up to 2 or 3 mm. in diameter, embedded in a fine-grained light grey matrix. The phenocrysts, which form as much as 25 per cent of the volume of the rock, are andesine Ab_{60} An_{40}. The matrix in which they are embedded has an average grain of 0·03 mm., and consists of chlorite and andesine in about equal proportions. The chlorite forms fine needles and is probably secondary after actinolite. The needles have a pronounced parallel arrangement, giving the rock a definite schistosity. The feldspars are more or less altered to epidote, calcite, and kaolin.

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The feldspar porphyry not only cuts across the bedding of the Rice Lake lavas, but forms sill-like bodies parallel to it. It is cut by the diabase dykes of the district. It was intruded after the first main period of faulting, as is shown by the fact that where dykes meet shear zones they either cut across the sheared material or turn and follow the shear, often fingering into the sheared material to form a number of small parallel dykes separated by bands of schist. The dyke material in such places is not itself sheared, but in places is greatly fractured, indicating that some movement took place after intrusion.

DIABASE

The latest igneous rock in Rice Lake district, except the later granite, is a diabase which forms very numerous dykes, of all sizes up to 300 feet in width. Dykes of the same material are very common also in the earlier granite north of Wanipigow river and lake. They were not observed in Oiseau River area.

The diabase is a fine-grained black rock, fine-grained even in dykes of considerable size. On the surface it is usually partly chloritized to some depth, and rather soft. It has been called diabase more because of its occurrence in dykes and to distinguish it from the nickel-bearing gabbro, than because of its diabase texture. In fact, the rock is so badly altered that any such texture, if it existed, has been obliterated. The thin section examined is a mass of alteration products in which almost all the original feldspar has been altered to epidote and most of the ferromagnesian mineral to chlorite. Some hornblende is present in large crystals that are probably original, as they do not possess the leafy or fibrous structure characteristic of a hornblende secondary after augite.

The diabase cuts the Rice Lake series, the earlier granite, and the feldspar porphyry dykes, and is, therefore, later than they. It is cut off by the later granite, and is, therefore, older. When dykes of diabase meet a shear zone, they either cut across the sheared material, or turn and follow the shear zone, apparently replacing or absorbing an equal bulk of the sheared rock. The dykes are, therefore, later than the first period of shearing, but are themselves more or less fractured and sheared, especially at their edges. That there must have been some movement along the shear zones after the intrusion of the dykes is indicated at the shaft of the Gold Pan mine, where a diabase dyke cuts across a narrow shear zone, and the later movement along the shear zone has shifted the outcrop of the dyke laterally for a distance of about 20 feet.

GABBRO

Gabbro does not occur in Rice Lake area, so far as known. It was studied in Maskwa and Oiseau Rivers areas.

Petrography

The gabbro occurs in dykes and sills. The dykes are black or dark grey, medium-grained rocks. Their composition is uniform throughout, owing undoubtedly to rapid coolings that prevented any differentiation with resultant changes in composition. The material of the sills, on the contrary, varies greatly in composition from place to place. It will be shown that the variations are such as would be produced by the processes of differentiation acting while the great masses of molten rock were slowly cooling and crystallizing.

The Oiseau (Bird) River sill is more than 5 miles from east to west, and of variable width, the greatest being slightly over a mile. The variation in its composition is found along any line from north to south.

The sill is cut by dykes up to 3 or 4 feet in width of light grey, white, or pinkish aplite. They are apparently confined to the gabbro and there is no later intrusive in the region, from the differentiation of which they might have been formed; hence they undoubtedly represent a siliceous differentiate of the gabbro magma.

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They are all highly siliceous rocks, quartz forming from 40 per cent to 70 per cent in different dykes. The remaining constituent is nearly all albite, though a little muscovite and biotite are nearly always present. The greatest amount of ferromagnesian constituent noted in any section examined was 5 per cent. Most of the dykes are more or less porphyritic, made up of phenocrysts of quartz and albite up to 2 mm. in diameter embedded in a matrix of about 0·1 mm. average grain.

The southernmost rim of the sill, which is exposed in one locality only, on the line between sections 27 and 28, is a light grey, rather fine-grained, equigranular rock. It consists of 75 per cent to 80 per cent of andesine feldspar ($Ab_{60}An_{40}$), 15 to 20 per cent of tremolite, and perhaps 4 per cent or 5 per cent of fine-grained quartz. The grain averages about 0·5 mm. This material forms an east-west band some 20 feet in width, the southern edge of which is covered with drift. On the north side it grades rather suddenly into rock of somewhat darker colour but about the same grain, consisting of about 30 per cent tremolite, andesine feldspar ($Ab_{60}An_{40}$), and a few scattered grains of quartz, and forming a band about 15 feet wide. A still darker coloured and somewhat coarser-grained rock succeeds that last described, grading into it at the contact. In it, actinolite, a hornblende containing iron, takes the place of tremolite, which contains no iron, and there is 50 per cent to 60 per cent of it present, in place of the smaller proportions of the bands to the south. The actinolite forms an interlacing network of cleanly crystallized laths, and andesine of the same composition as before ($Ab_{60}An_{40}$) forms small grains filling the interstices between the laths. A very few grains of quartz are probably present. Zircon is accessory.

The latter band grades on the north into the normal medium-grained feldspathic gabbro of the top of the sill, composed of about equal parts of common hornblende, and andesine (Ab_{60} An_{40}), with a little quartz, zircon, apatite, and calcite. The feldspathic gabbro gradually becomes coarser in texture northward, and so merges into the very coarse-grained, highly feldspathic type that forms roughly the southern third of the whole sill. It consists of about 75 per cent of labradorite feldspar (Ab_{30} An_{70}), and green hornblende, with accessory biotite, magnetite, and titanite. The grain of the crystals averages about 4 mm., and the large crystals of feldspar, which show no sign of alteration, are crowded with small lath-like inclusions of the hornblende. The hornblende also occurs in large original crystals.

The coarsely crystalline material described gives place in turn to a medium-grained, dark grey diorite or gabbro, that near the contact of the two types is composed of about 65 per cent of labradorite ($Ab_{30}An_{70}$ to $Ab_{35}An_{65}$) and 35 per cent of actinolite—in small laths about 0·1 to 0·15 mm. in length. The average grain of the feldspar is less than 1 mm. This medium-grained, dark grey rock forms the northern two-thirds of the sill.

At the contact of the medium-grained type and the coarse feldspathic type, there is a broad zone of hybrid rock, consisting of a matrix of the medium-grained type that surrounds and encloses great numbers of blebs of very coarsely crystalline material. The blebs are of all sizes up to 50 feet in length, of very irregular shape, with rounded flowing outlines; at their edges they show a rapid gradation, within about an inch, into the finer-grained material of their matrix. Their composition is like that of the feldspathic material on the south, but, if anything, slightly coarser in grain and more feldspathic.

The medium-grained material that forms the northern two-thirds of the sill appears in the field to be of much the same composition throughout, except at the northern edge. Under the microscope, however, differences may be observed. The hornblende of the rock on the south is displaced by augite toward the north, and the proportion of augite to feldspar gradually increases. The feldspar remains of much the same composition, but decreases in proportional amount. The rock thus changes from a hornblende to an augite gabbro.

At the north boundary of the sill, feldspar disappears entirely, or almost so, and the bulk of the rock consists of augite crystals, crowded together. The augite is

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colourless in thin section, and perfectly fresh. For 6 or 8 feet from the northern contact the rock is finer in grain than elsewhere, the result presumably of chilling. The crystals in the chilled zone average 0·05 mm. in diameter, and are approximately equidimensional. This matrix of fine-grained, fresh augite crystals contains augite crystals of much larger size, up to 1·2 mm. diameter, but otherwise like the crystals in the matrix.

The matrix also contains crystals of common green hornblende up to 12 mm. or more in length and commonly gathered together in small blebs up to a foot in length. Most of the hornblende crystals are fresh, but some of them have suffered an alteration that will be described later. Finally, sulphides and oxides of various kinds are present. Pyrrhotite is the sulphide, magnetite the oxide, present in greatest amount, and chalcopyrite, pentlandite, and ilmenite are minor constituents. They may be aggregated in solid masses, or scattered in grains of various sizes.

The changes in composition from south to north may be summarized as follows:

1. Quartz diorite—quartz, andesine, tremolite.
2. Quartz diorite—andesine, actinolite, a little quartz.
3. Quartz diorite—andesine, common hornblende, a little quartz.
4. Hornblende gabbro—labradorite, hornblende; coarse-grained, highly feldspathic.
5. Hybrid phase—mixture of 4 and 6.
6. Hornblende gabbro—labradorite, hornblende; less feldspathic than No. 4, medium-grained.
7. Augite gabbro—labradorite, augite.
8. Augite—pure augite, with blebs of hornblende, magnetite, and sulphides.

Differentiation

The above table indicates a uniform variation in the specific gravity of the various rock types between the south and north edges of the sill. The specific gravities of the different minerals present are: quartz, 2·66; andesine, 2·67; labradorite, 2·713; tremolite, 2·93; actinolite, 2·99; hornblende, 3·11; augite, 3·1–3·2; pyrrhotite, 4·6; chalcopyrite, 4·2. Without making specific gravity determinations of the various rock types it is evident that the rocks on the south side are aggregates of the lighter minerals, and that the specific gravity of the various mixtures must increase continuously to the northern edge, where the rock is composed exclusively of the heaviest minerals, augite, hornblende, and the sulphides. A variation of this sort is only produced, so far as known, by the action of gravity on a molten mass of rock throughout a long period of time. The action causes the heavy constituents of the crystallizing rock magma to seek the bottom of the igneous mass, whereas the lighter constituents naturally take up their positions at the top. This process, by which a magma of originally uniform composition is separated into rocks of widely different composition, is known as differentiation.

Several theories have been advanced as to the method by which differentiation is brought about. A detailed consideration of these is out of place in this report, but the most plausible, in the writer's opinion, is that advocated strongly in recent years by Bowen,[1] which supposes that during the slow course of crystallization of a body of magma, the first-formed crystals sank through the hot liquid toward the bottom of the sill. Although any constituent present in large amount may crystallize first, the first crystals formed are usually those of basic minerals, such as magnetite, ilmenite, sulphides, olivine, pyroxene, and hornblende. Each of these minerals contains relatively larger proportions of iron, magnesia, lime, and alumina, and smaller proportions of silica, potash, and soda, than an original gabbro magma. Their crystallization and sinking, therefore, leave the upper parts of the magma richer in silica, soda, potash, and volatile constituents than at first, whereas the lower parts are enriched in the constituents carried down, i.e., magnesia, iron, lime, and to some extent, alumina. As long as this process continues, therefore, the upper parts of the magma become more siliceous, the lower parts more basic.

[1] Bowen, N. L., Journal of Geology, vol. 23 (1915), Supplement.

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The facts supporting this step, supplied by a study of the Oiseau River sill, may be listed as follows:

The uniform increase in the specific gravity of the different parts of the sill, from south to north, indicates that a gravitative differentiation has occurred.

The composition of the minerals, taken in conjunction with the proportions in which they are present in the different rock types, shows that southern types are relatively rich in silica and soda, whereas lime and magnesia are small in amount, and iron is altogether absent. The northern types, on the contrary, are very rich in iron, magnesia, and lime, with minimum amounts of silica and little or no soda.

Hornblende, mica, and quartz are all minerals that characteristically crystallize from "wet" magmas, that is, magmas containing a good deal of water and other volatile constitutents, whereas, augite is equally characteristic of "dry" magmas, containing small amounts of water. The presence of hornblende, mica, and quartz in the southern parts of the sill, and of augite in the more northern parts, indicates that the volatile constitutents of the magma were segregated in the southern parts, in the manner required by the hypothesis.

The above tends to prove gravitative differentiation, without favouring the method of differentiation advocated by Bowen above those advanced in other theories of differentiation. The following facts, however, prove more definitely that crystal sinking occurred:

The large crystals of augite in the finely crystalline augite of the north edge of the sill may have sunk to their present position from higher levels. On the contrary, they may also have formed in place, like phenocrysts, having commenced their crystallization sooner than the crystals of the matrix, and thus had a longer period of growth. In itself, therefore, the presence of these crystals constitutes no decisive proof of sinking, but their association with large hornblende crystals does indicate sinking. The hornblendes cannot be phenocrysts formed in place, as the conditions requisite for the formation of hornblende and augite differ considerably, and if phenocrysts were formed in place at all, they were augite phenocrysts. The hornblendes could, therefore, attain their present position, only by sinking from the upper levels of the magma where, as the composition of those parts shows, it would form.

The blebs of coarsely crystalline feldspar and hornblende found at the southern edge of the medium-grained hornblende gabbro zone (No. 5, page 16) are explained in a similar way. The large crystals of which the blebs are composed must have commenced their crystallization sooner than the comparatively small crystals by which they are surrounded and would be among the first crystals to form in the liquid magma. But the labradorite crystals, instead of being heavier than the surrounding magma, as were the hornblendes, were lighter, and would tend to float up through it. Rising, they would encounter other crystals and be rafted with them to form the aggregates now found. During this process a number of hornblende crystals were included in the rafts, but the feldspars were apparently sufficiently lighter than the surrounding magma to support these. They would rise through the molten magma, become more acid and lighter upwards, until they reached the horizon at which the specific gravity of the liquid was equal to that of the crystal masses, and would float there until consolidation took place.

After the magma hardened into solid rock, further cooling was undoubtedly accompanied by cracking. Into the fissures so formed flowed the still liquid, highly siliceous residues of the magma, forming the present aplite dykes.

Nomenclature

As the writer, in naming the rock of the sill gabbro, instead of norite, differs from previous writers on the subject, it may be well to summarize briefly the evidence for doing so.

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The writers mentioned—R. J. Colony and W. S. McCann—studied the Maskwa River sill, a body identical with the Oiseau River sill in every respect, lying 12 miles to the north. Colony's statement as to the petrography of the sill is as follows:[1]

"The norite is of simple composition, but varies both in texture and mineral make-up to some degree because of differentiation. In general it is composed almost wholly of basic feldspar ranging from andesine to labradorite, and carries as the only ferromagnesian component a green amphibole, or actinolite, derived by uralitization from a former magnesian pyroxene, probably hypersthene. One of the most striking features of the rock is the manner in which the uralitized pyroxene encroaches upon, cuts through, and penetrates the feldspar (which is otherwise perfectly fresh and unaltered) in every conceivable direction; it is clearly a product of magmatic end-phase-consolidation matters upon an original containing both magnesia and iron, i.e., hypersthene."

McCann makes no statement as to the petrography of the "norite," beyond stating that "The following petrographic description of the norite by Dr. R. J. Colony agrees with the present writer's observations."

It appears from the above description, therefore, that the rock specimens collected and studied by Colony did not contain any pyroxene, but only hornblende, corresponding thus to those from the southern half of the Oiseau River sill; and, further, that finding it naturally difficult to believe that sulphides would be segregated from a rock with composition such as he described, he concluded it better to assume that the hornblende was formed by the alteration of a hypothetical primary mineral, hypersthene, even though no remnant of such an original mineral is left, or no indication that such an alteration had taken place is to be seen.

The writer's examination indicates that augite, not hypersthene, is the pyroxene present in the intrusive. It is possible that a more detailed examination might reveal hypersthene or enstatite, but none was found in the three thin sections from the basal parts of the sill that were studied. The rock is, therefore, properly a gabbro rather than a norite.

Neither can the writer agree with Colony that the hornblende has resulted from the alteration of pyroxene. The hornblende forms massive, often very large crystals, lacking entirely the leafy structure usually found in the alteration product of pyroxene. Again, it rarely happens that large crystals of pyroxene alter to hornblende so completely that there are not some small remnants of pyroxene remaining in some of them. Nothing of the sort is here observable. Further, numerous small crystals of hornblende enclosed in large crystals of perfectly fresh labradorite are to be seen in many thin sections. If these are alteration products of pyroxene it is difficult to see how solutions could have saturated the feldspars so completely as to cause the alteration, without at the same time altering the feldspar. Finally, the augite found in the basal parts of the sill is without the smallest sign of alteration, even where filled with blebs and veinlets of sulphide, where alteration might naturally be expected.

The writer has, therefore, concluded that the hornblende present is not an alteration product of pyroxene, but was normally formed during the crystallization of the upper parts of magma; presumably because there was in these parts a concentration of the water and other volatile constituents of the magma.

Structural Relations

Structure of the Intrusive. The large mass of gabbro in Oiseau River area parallels the bedding of the Rice Lake series in a general way, and, therefore, is termed a sill. For a great part of its length the intrusive has followed the contact of the granite and Rice Lake series, but toward its west end it has left this contact and broken across the Rice Lake series to the contact between the volcanics and the sediments. The north contact of the gabbro and granite, seen in several places, is vertical or steeply inclined to the south, corresponding to the general dip of the Rice Lake series.

[1] Colony, R. J., Bull. C.I.M.M., No. 103, p. 867.

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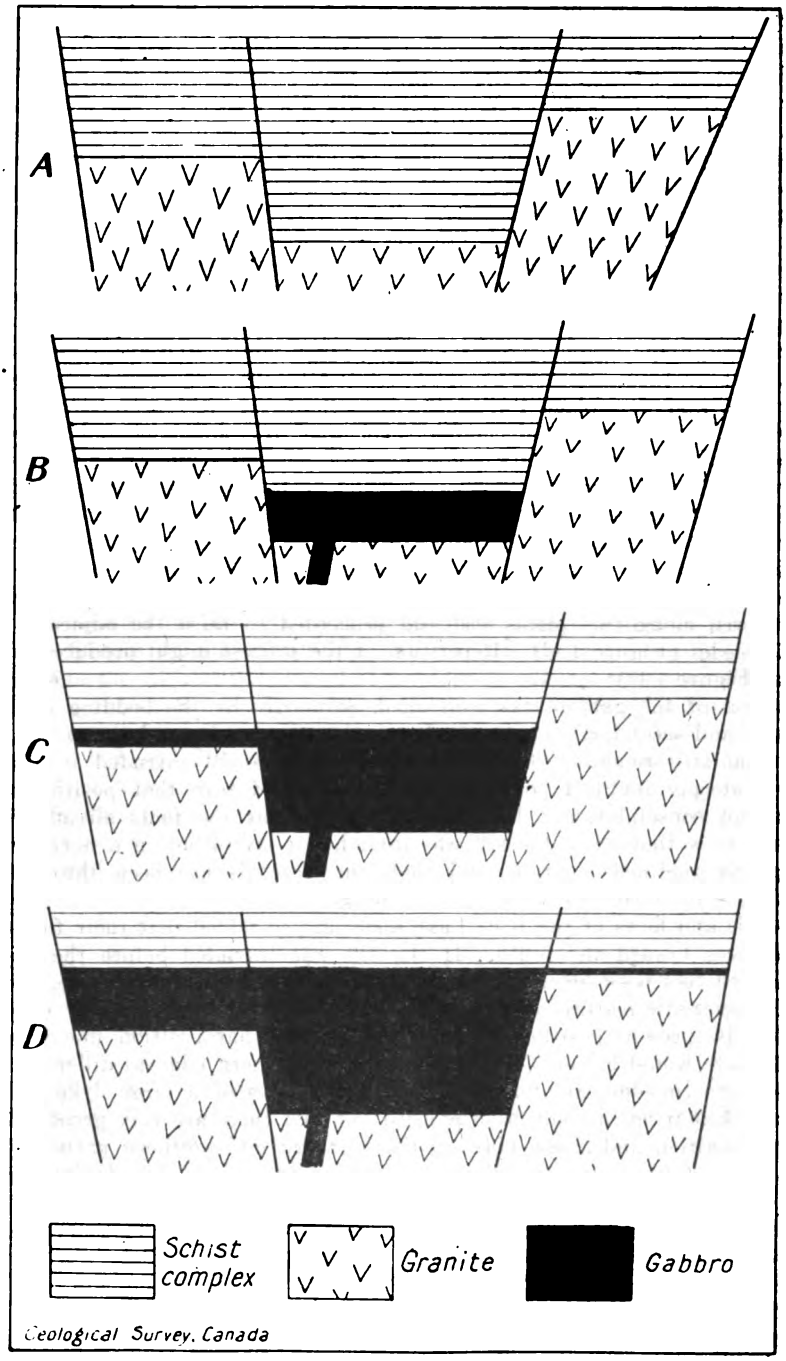

Figure 4. Diagram showing a possible mode of intrusion of the gabbro of Oiseau Lake area.

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Detailed mapping of the boundaries shows that the gabbro does not form a normal sill, however, but is made up of a number of sections of different widths. The width of the individual sections is nearly uniform from end to end, and the strike of each section is approximately parallel to that of the adjacent Rice Lake series. The narrowest section is only about 500 feet in width; the widest over 6,000 feet. At the junction of two sections, the end of the wider is a straight line running nearly north and south.

The mapping also shows that all the changes in width are effected by the shifting of the north boundary only; the south boundary of the sill is a gently curving line with a general east and west direction. In section the sill, therefore, looks like a succession of rectangular blocks of different thickness, placed end to end on a gently curving surface.

Search for the cause of these peculiarities revealed that the north-south lines bounding the ends of the thicker blocks are faults that have formed belts of schist of varying width in the older rocks but did not fracture and displace the gabbro, since its southern boundary is not displaced. The faults were there before the gabbro was intruded, and merely controlled the intrusion.

An attempt to portray the possible mechanics of the intrusion has been made in Figure 4. Figure 4 A represents the supposed original structure of the rocks after faulting had occurred, and before the intrusion of the gabbro. The gabbro may be supposed to have entered first into the deeper fault blocks, splitting them apart along the contact of the granite and Rice Lake series, and raising bodily the overlying mass of Rice Lake series (Figure 4 B). When the block was raised so far as to bring the gabbro up to the granite—Rice Lake series contact in the next fault-block, the gabbro entered along this plane also and proceeded to raise the adjacent block of Rice Lake series (Figure 4 C). Repetition of the process might produce the present condition (Figure 4 D).

Intrusion of the gabbro was controlled, primarily by the bedding of the Rice Lake series, and secondarily by the faults cutting that series and the earlier granite. The question still remains to be considered, was the sill intruded in its present vertical or steeply inclined position, or was it folded into that position after its intrusion and consolidation. The writer believes that the facts already presented support the view that when the sill was intruded it lay either in a horizontal or at most a gently inclined position, and that, therefore, it has been thrown into its present steeply inclined position by later folding.

The beds and flows of the Rice Lake series are so folded that their former upper side now faces toward the south. If the sill was intruded before the Rice Lake series attained this position, its south side should also be the upper side, and should exhibit characteristic features accordingly. On the contrary, if the gabbro was intruded in its present position, and has maintained that position unchanged since intrusion, there would be no reason to expect the southern edge to differ in any way from the northern edge, any more than the two edges of a large dyke differ from each other. But it has already been pointed out that there are very great differences, both in composition and grain, between the northern and southern parts of the sill; and that these differences are such as could be produced by gravitative differentiation. In fact the differences are identical with those produced by gravitative differentiation in gabbros that have been undisturbed since consolidation; and whose original top and bottom are, consequently, definitely known.

The variations in the composition of the sill, therefore, indicate that it once lay in a flatter position than at present, and that it has been so folded as to make the original upper side face the south. There are two other facts tending to confirm this conclusion. The granite on the north side of the sill is filled with dykes of gabbro trending toward the large sill, but no such dykes occur on the south side. If the sill was originally flat-lying, the dykes were probably its feeders, and as such must lie on its original lower side. If the sill was intruded in a vertical position originally, there would be no need for such feeders, and the dykes must be supposed to be merely

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offshoots of the larger body; in which case it is difficult to see why they should be confined to the north side of the sill.

Finally, intrusion of the sill was controlled by the faults of the region, in such a way that the inflowing igneous rock pushed out the rocks on the present south side, giving the south side a smoothly flowing outline. This is conceivable if the sediments now forming the south side were flat-lying at the time of intrusion, and hence free to move upward, but it is very difficult to explain if the rocks at the time of intrusion lay in their present position, for intrusion must in the latter case have been accompanied by great horizontal compression.

The writer believes that these reasons justify the conclusion that the Oiseau River sill has been tilted into its present position since its intrusion. It has already been shown, however, that the first period of folding undergone by the Rice Lake series preceded the period of faulting, and probably preceded or accompanied the intrusion of the earlier granite. Yet the gabbro sill was intruded *after* faulting, and lay almost flat during its consolidation. To reconcile these apparently inconsistent facts we must conclude that the first period of folding affecting the Rice Lake rocks was not very severe and produced rather low dips, not over 20 degrees or 30 degrees perhaps. The gabbro could have been intruded as a sill into rocks with such dips, and still have undergone the gravitative differentiation it now exhibits. It is of interest in this connexion that there is good evidence to prove that the first folding affecting the Keewatin rocks to the south of James bay gave these rocks dips of about 20 degrees.

Relations to Other Formations. The gabbro is found in contact with only three of the rock formations of the district, the Rice Lake series, and the earlier and later granites. Its relations to the dyke rocks of the Rice Lake area are, therefore, undetermined. The feeders of the gabbro sill cut through the earlier granite in Oiseau River area, and the sill itself is chilled at the edge in contact with the earlier granite. It, therefore, is intrusive into the earlier granite, and into the older Rice Lake series.

The gabbro is found in contact with the later granite in the Maskwa River area. Good contacts indicate that the granite is intrusive in the gabbro. At one sharp contact the massive coarse-grained granite is chilled to a fine grain, and possesses a distinct flow structure indicating movement of the chilled and viscous granite along the contact, whereas the gabbro, very coarse-grained and feldspathic, maintains its grain unchanged at the contact. In several other places dykes of granite cut the gabbro, but, unlike Oiseau River area, no dykes of gabbro were seen in the granite.

MASKWA RIVER GABBRO

Maskwa River area has been described by McCann in the Summary Report of the Geological Survey, 1920, and a report on the same district has also been made by R. J. Colony. These writers differ somewhat in their interpretation of certain facts, and both assign a structure to the Maskwa River gabbro different from that which the writer has shown the Oiseau River mass to possess. As similarities rather than differences might reasonably be expected in two bodies of nickel-bearing gabbro so close together, it seemed advisable to make a rapid trip into Maskwa River area in order to compare the two gabbros, and to obtain data that might reconcile the differences in interpretation. In addition, it was decided to examine another body of gabbro reported a short distance to the east of that described by McCann.

McCann and Colony show by the structure sections accompanying their maps that they consider the Maskwa River gabbro to be a stock-like mass, that is, a body whose depth is as great or greater than its length. The Oiseau River gabbro, on the contrary, is a sill, or pancake-shaped body; and in addition, the sill has been tilted on edge. The economic importance of determining the structure correctly is obvious. If the Maskwa River body be a stock, there is no reason why nickel ores may not be found at any point along the outer edge; and, since the ore minerals tend to sink through the molten rock, rather than to move toward the sides, concentration would not, probably, be great enough at the sides of a stock to make valuable ore-bodies. If

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on the other hand, the mass be a tilted sill, like that at Oiseau lake, the ores will be found along one edge only, the original lower edge, and concentration might be great enough to form ore-bodies.

McCann and Colony differ in their interpretation of the geological relationships of certain masses of Rice Lake lava within the limits of the Maskwa River intrusive. McCann regards them as mere inclusions—bits of lava broken off during the intrusion of the molten gabbro, that floated around in it until it consolidated. Colony, on the other hand, considers them as parts of the roof or base of the mass brought into their present position by faulting. Colony accordingly maps the gabbro and Rice Lake series in alternate parallel belts separated by faults, whereas McCann maps the gabbro as a single large mass containing isolated bodies of Rice Lake lavas.

If Colony's interpretation were correct, and the masses of lava were parts of the base on which the intrusive lies, the fact would be of the greatest importance to the prospector, as nickel ores might be expected to occur along all the contacts of the gabbro and Rice Lake rocks, and the area favourable for prospecting would be enormously increased. If they are downfaulted parts of the roof, no ores would occur around them. If they are inclusions, then again they will not influence in any way the deposition of ore-bodies.

Examination of the Maskwa River body convinced the writer that it is similar in every way to the Oiseau River mass. Towards its north side it has the same very coarse grain and highly feldspathic composition that distinguishes the south side of the Oiseau River sill; and the coarse-grained material gives place successively to medium-grained hornblende gabbro, augite gabbro, and augitite containing large hornblende crystals, magnetite, and sulphides in exactly the same manner as described for the Oiseau River sill. All the sulphide concentrations occur along one side of the body of gabbro—the south side. The writer, therefore, concluded that the Maskwa River mass is also a tilted sill, that differs from the Oiseau River sill only in having the upper side facing north instead of south. Evidently the Maskwa River sill lies on the north side of the anticline of which the Oiseau River sill forms the south side.

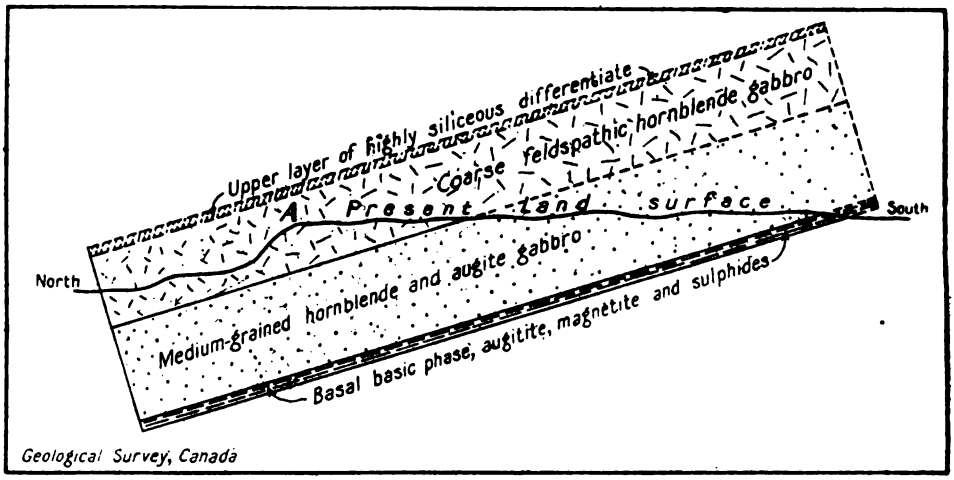

Figure 5. Diagram showing inferred structure of Maskwa River sill and the removal of its upper part by erosion. The most feldspathic differentiate occurs at A.

The Maskwa River sill does not, however, appear to be tilted into a vertical position, like the Oiseau River sill, but to have rather a low northward dip of 20 degrees or 30 degrees. This conclusion was drawn because the most feldspathic differentiate does not occur at the northern edge of the sill, but 20 to 25 chains to the south, and at a higher elevation. Figure 5 illustrates the relations that occur, and the inferred structure.

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The writer then investigated the contacts of the bodies of Rice Lake series lying within the gabbro mass. If these bodies are really parts of the original roof or basement of the sill, the gabbro should show chilled edges against them, for such chilled edges are prominent features of true contacts, and are 5 or 6 feet in width. On the contrary, if these masses are merely inclusions, broken off by the fluid gabbro, and floating around in it until it became consolidated, they would have become thoroughly heated by the time consolidation occurred, and the gabbro in contact with them would not be chilled, but would crystallize coarsely. Examination showed that the contacts are not chilled, and, further, that the bodies of Rice Lake series have undergone strong heating, or baking, as might be expected if they are inclusions. Again, there is no difference in the composition of the gabbro on the two sides of a body of Rice Lake lava. If the lava was a part of the original basement or roof of the sill, such a difference in composition would be inevitable. The bodies of Rice Lake series within the limits of the Maskwa River intrusive are, therefore, not parts of the original roof or basement of the sill, brought into their present position by faulting; but are merely inclusions or roof pendants, as McCann concluded. It follows that they have no influence on the deposition of the copper-nickel ores, and that only along the main southern contact of the sill with the Rice Lake series may such ores be expected to occur in paying quantities. The writer may add that his traverses indicate that the inclusions of Rice Lake series are shorter and rounder than as mapped by McCann.

An important shear zone, striking north 70 degrees west and dipping 50 degrees south where observed, cuts the Maskwa River gabbro, crossing the west boundary of surveyed timber limit 2692 about 25½ chains south of Cat Creek crossing and 9½ chains south of post marked T.B. 2692. The shearing has converted coarse feldspathic gabbro into a highly fissile schist. Two belts of schist, 4 feet and 2 feet wide respectively, were observed, separated by 3 or 4 feet of unsheared rock. Information received from prospectors indicates, however, that further belts of sheared rock are present, though concealed by drift where the writer made his observations. The rock on both sides of the fault is the coarse feldspathic gabbro. There is strong magnetic variation in the neighbourhood of the sheared zone, probably due to the recrystallization of some of the iron of the gabbro as magnetite, during the shearing.

The writer also visited the newly-discovered body of gabbro lying to the east of the body described by McCann. Time did not permit of the mapping of this body, which is about one-half mile in width from north to south, and is said to be at least 2 miles long. It is heavily covered by clay and wind-blown sand, so that outcrops are scattered. A number of mining claims have been staked on this body by Messrs. D. A. McLeod and A. Campbell, whose camp is situated near its west end, and about 3½ miles, by trail, east of Restawhile camp on Cat creek (See map No. 1841, by W. S. McCann).

The newly-discovered body is bounded on both the north and south sides by the later granite. Good proofs were obtained that the granite is intrusive into the gabbro. The granite has stoped away almost all the Rice Lake series into which the gabbro was originally intruded, and has even cut into the sill itself. The original edges of the sill being thus removed, it is improbable that good ore-bodies will be found along the contacts. If parts of the lower contact can be found, along which there still remains some of the older Rice Lake series, such places might be worth prospecting.

Like the Maskwa River sill, this one appears to lie at a low angle, with a dip to the north, so that the southern edge is the one along which deposits, if present, are likely to occur.

LATER GRANITE

The later granite occurs around Maskwa river from the mouth to the nickel deposits; on Winnipeg river from Maskwa river down to lake Winnipeg; and up Manigotagan river from lake Winnipeg to Clearwater lake. It may occupy the whole of the belt between these districts.

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Petrography

The later granite is a coarse-grained, grey, white, or pink rock, commonly equigranular, but locally exhibiting strong porphyritic textures. The composition appears to vary somewhat in thin section, different sections containing from 10 per cent to as much as 40 per cent of quartz. The ferromagnesian mineral is either all biotite, or a mixture of hornblende and biotite. It is usually small in amount, although forming perhaps 15 per cent of the rock around Maskwa lake. A little muscovite, apatite, and zircon may be present. The feldspar is largely or entirely albite or albite-oligoclase, variations in composition from pure albite to Ab_{70} An_{30} being observed in different districts. Microcline may also be present, in greater or less amount. In a section from the mouth of Maskwa river microcline forms two-thirds of the total feldspar; in a section from the neighbourhood of the Maskwa River nickel deposits, about one-fourth; and in a section from Clearwater lake, on Manigotagan river, no microcline was observed.

In places the granite exhibits gneissic phases, due to the flow movements of the viscous magma during consolidation, and to digestion of inclusions.

Metamorphism of Rice Lake Series

Around Clearwater lake (Rice Lake district) the intrusion of the later granite has strongly metamorphosed the older Rice Lake series. Along the contact there is a zone of Rice Lake series about half a mile in width, that has been so metamorphosed and intruded lit-par-lit by the granite, that it is almost impossible to draw a boundary line between the two. The boundary, shown on the map, represents the southern boundary of unaltered Rice Lake series, to the south of which lies the one of granite dykes and altered Rice Lake rocks, all mapped together with the granite.

The alteration of the Rice Lake lavas in the contact zone appears to have been largely a granitization; that is to say, the older rocks seem to have absorbed, like a sponge, much siliceous and feldspathic material from the granite. This material, entering along planes of schistosity and other channels, acidified the older rock both by admixture and by combining chemically with some of the more basic constituents. The resulting rocks are hybrids, like neither of the parents, but with some of the characteristics of both. Most of them retain more or less perfectly the bedding or schistosity of the Rice Lake lavas and their greenish colours; but differ in being highly quartzose, more feldspathic, and coarser grained.

Structural Relations

Jointing and Faulting. The later granite is cut by numerous joints and faults with small displacements, not exceeding a couple of inches. Large faults with wide, sheared zones, such as are found in the older rocks, do not occur in the later granite. Where such belts of schist strike from the older rocks towards the granite, they are cut sharply off at the contact, and the projection of the fault line is marked merely by a joint. Evidently the later granite was intruded subsequent to the main periods of faulting, but slight movements, of sufficient strength to joint the granite and fault it slightly, followed the intrusion.

The jointing in the granite follows the same trends as the earlier faults of the district. There are in all three or four sets of these joints and small faults, which, although undoubtedly produced all within a short time, exhibit a definite sequence of formation.

The first to be formed comprises apparently two sets, one striking north 10 degrees east, the second north 50 degrees east, although there is some variation from these directions. Those striking north 10 degrees east seem to be merely joints, without horizontal displacement of any kind between the two sides; but thin seams of black gouge-like material in them suggest that there might have been a little

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vertical movement. Those striking north 50 degrees east are distinct faults, with small horizontal displacements. The northwest side has been shifted toward the southwest.

A third set of small faults has a general strike of north 20 degrees west. In these the east side is displaced horizontally toward the south, like the larger faults in the Rice Lake series. These small faults are distinctly later than the first set of joints, for joints between a pair of the faults have been rotated and widened (Figure 6). Their relations to the faults striking north 50 degrees east are not definitely known.

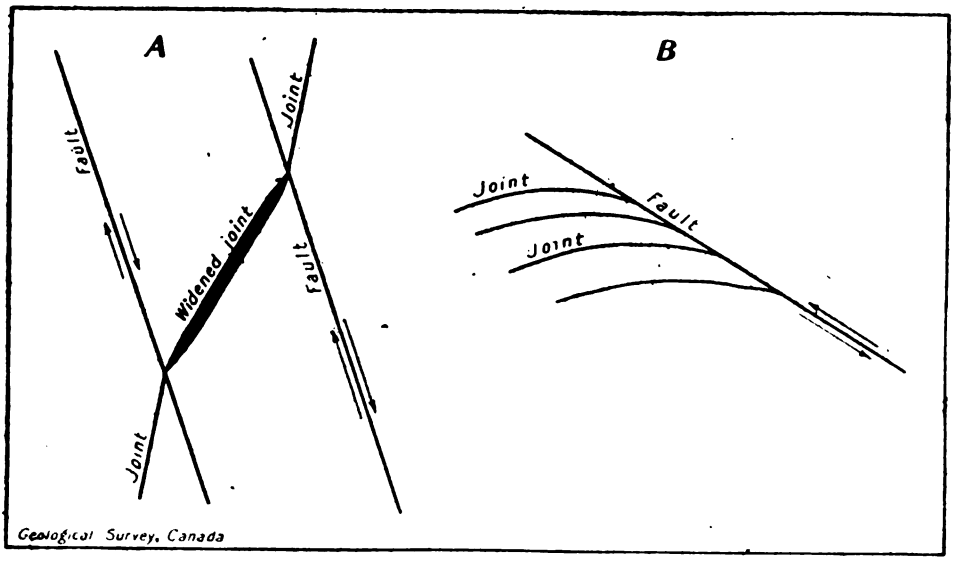

Figure 6. Diagram showing: (A) rotation and widening of a joint between two small faults; (B) relation of joints to a fault.

All these joints and faults are filled locally with thin dykes of aplite, indicating that they must have been formed very soon after the consolidation of the granite, while there was still some liquid siliceous magma left to fill them.

The last set of small faults has a general strike of north 70 degrees west. Movement along them has been almost horizontal, as shown by the direction of the fault striæ, which rarely dip more than 30 degrees. The north side of these faults has been quite uniformly shifted toward the west, as shown by the displacement of small aplite dykes. These faults are commonly filled with hard vitreous quartz, probably the last exhalation of the granite magma. In places the quartz has been shattered, implying slight further movement after the deposition of the quartz.

The formation of the latter faults has been accompanied by jointing of rather irregular direction. Figure 6 B shows the connexion of the joints with a fault, and indicates the variation in their strike. Slight movement along the joint planes may also be observed.

Relations to Other Formations. The later granite intrudes all the other rocks of the region, and hence is the youngest rock present. In Maskwa River area it cuts into the gabbro, sends dykes into it, and shows a chilled edge with a gneissic texture against it. In Rice Lake area it intrudes and metamorphoses the Rice Lake series, and cuts off the diabase dykes that intrude it. Dykes of the granite also pierce the Rice Lake series, and cut across all the other dykes of the vicinity.

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CORRELATION

No extensive correlation of the eastern Manitoba district with others can be attempted at present, both on account of the lack of work in intermediate areas, and the scantiness of the geological record in the areas studied. However, attention may be called to the similarity of the granites to those described by Lawson in the Rainy Lake area 150 miles to the southeast. Lawson states[1] that in the Rainy Lake area there are granites of two ages. The older, which he terms Laurentian, has suffered from marked deformation and shearing, whereas the younger, termed by him Algoman, is typically fresh and unsheared. The similarity to the granites of eastern Manitoba is self-evident, and it seems probable, therefore, that the Manitoba granites were intruded at the same time as those around Rainy lake.

The Rice Lake series bears the same relation to the earlier granite as Lawson's Keewatin bears to his Laurentian granite. The Rice Lake series may, therefore, be tentatively correlated with the Keewatin of Rainy lake.

ECONOMIC GEOLOGY

Nickel-Copper Deposits

Discoveries have been made in Oiseau (Bird) and Maskwa (Bear) River areas of bodies of sulphides containing considerable quantities of nickel and copper. Those at Maskwa river have already been described by McCann.

The principal ore mineral in both districts is pyrrhotite containing more or less pentlandite and chalcopyrite. Ilmenite and magnetite are also present in large quantity. In each district the ore minerals are concentrated within the gabbro near the original base of the sill. In Oiseau River area this is the northern contact; in Maskwa Lake area the southern contact. Elsewhere in the sills only an occasional grain of sulphide or magnetite may be found here and there.

The sulphides and oxides do not occur in veins, but as irregularly shaped accumulations, or segregations, within the gabbro. In places the concentration has been sufficient to form solid masses of ore minerals several feet in thickness. Where less concentrated, the ore minerals are mixed with varying amounts of the minerals of the gabbro. There is no sharp boundary between a mass of ore and the surrounding rock; the proportion of ore minerals very gradually decreases, and that of the rock minerals increases, until pure gabbro results.

The concentration along the lower edge of the sills ranges from solid masses of sulphide or oxide in one place to sparse accumulations too lean to form ore in other places. From north to south, however, the concentration varies more uniformly, being always greatest near the former bottom of the sill and becoming rapidly less upward. The basal zone containing a notable proportion of sulphides is rarely over 100 feet in thickness, and commonly less.

The facts that the sulphides are scattered throughout the gabbro, and the rock minerals form everywhere the gangue in which they occur, indicate that they, together with the magnetite, are original constituents of the magma. They are the heaviest constituents of the rock, and are everywhere found concentrated along the original base of the sill, and they, therefore, like the augite and hornblende of the rock, sank while the main part of the intrusive was still liquid. Hence the ordinary processes of gravitative differentiation have caused the primary concentration of the sulphides, as at Sudbury.

Examination of thin sections of ore and rock from the base of the sill shows, however, that processes of secondary concentration have also been busy. The large crystals of green hornblende are in places cracked across, and solutions entering the cracks have leached the iron from the green hornblende, forming a colourless variety, tremolite, for from one-fourth to one-half millimetre on each side The alteration

[1] Lawson, A. C., Geol. Surv., Can., Mem. 40, 1913.

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may extend for several times this distance, along cleavage cracks in the hornblende. The tremolite so produced may be massive and optically continuous with the original hornblende, extinguishing with it; or it may form a multitude of grains, laths, and fibres. Calcite and sulphides fill the fissures, and also to a small extent replace the tremolite; the sulphide appears in places to be slightly later than the calcite, and to replace it. Small grains and strings of sulphide are also to be seen filling the interstices between the laths and grains of tremolite.

In other places sulphide fills small discontinuous cracks in the augite matrix. The augite on the sides of such cracks shows no sign of alteration. Other similar cracks are filled with tremolite fibres. Certain large crystals of hornblende have been completely altered to masses of tremolite fibres, and masses of sulphide have formed around the edges of all such altered crystals; grains and strings of sulphide fill spaces between the fibres.

The whole set of phenomena is worthy of more detailed study than the writer has been able to give it. The facts obtained indicate, however, that the sulphides, primarily concentrated in their present position by gravity, have been more or less brought into solution again and redeposited by solutions, or vapours, acting about the time of consolidation of the norite. The cracks mentioned as occurring in the augite matrix, filled with sulphides, are so discontinuous, running for perhaps 10 or 15 mm. and then ending in massive rock, that they must have been formed before the rock was completely hardened, so that fissures closed at once unless they were filled. The leaching of the iron from the hornblende implies the presence of solutions or vapours rich in sulphur; at the same time the amount of sulphide surrounding an altered hornblende crystal is many times too great to have been formed from the iron of the hornblende alone. The freshness of the augite likewise implies that the solutions of vapours were acting at a very early stage in the consolidation of the magma; had they been much later and cooler, the augite would probably have suffered alteration, as it would not have been in equilibrium with them.

To sum up: it is concluded that the oxides and sulphides were brought into their present position by sinking through the liquid gabbro. As the gabbro consolidated, cracking slightly at the same time, solutions or vapours carrying sulphur and iron permeated it, leaching iron from the hornblende, altering the hornblende to tremolite, and depositing iron sulphide in cracks and in and around the altered hornblendes. Singularly, there appears to have been some formation of calcite also, although the data on this point are not very definite. Prospecting should be confined to the former bases of the sills, the northern edge in Oiseau River area, the southern edge in Maskwa River area. At Sudbury the richest deposits have been found in former holes and depressions in the base of the sill, owing to the natural tendency of the heavy sulphides to gravitate to the lowest part of the base. It is highly probable that the same tendency was operative in the districts under consideration, hence search should be made for such depressions.

Attention may be called to the fact that ore-bodies cannot occur in connexion with any bodies of gabbro other than the large sills that have undergone the differentiation described. Bodies of gabbro of all sizes are to be found in many places throughout the district—dykes, which even an untrained observer can see to be of similar composition from edge to edge. It is absolutely useless to search for ore-bodies in the neighbourhood of such masses; the effort is merely a waste of time and money.

Values

The values, in the discoveries so far made, are principally in nickel, although copper in some amount occurs locally. Prospectors reported to the writer that they had obtained up to 5 per cent of nickel from some of the solid masses of sulphides. A small grab sample taken by the writer from such a mass gave, on analysis, 3·07

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per cent of nickel, 0·07 per cent of copper, and 14·22 per cent of insoluble mineral matter.

Prospecting has not shown whether the discoveries so far made include any ore-bodies of commercial importance. Much more work should be done to determine the length, breadth, and depth of bodies already found, and further search should be made for new bodies before the district can be pronounced a potential producer.

Parts of the district are rather thickly drift-covered, making prospecting by the ordinary methods difficult and expensive. In view, however, of the magnetic quality of the deposits, due to their content of pyrrhotite and magnetite, the district is particularly suited to prospecting with the dip needle. A large area might be rapidly and cheaply traversed with this instrument, that requires for its proper use only elementary information, obtainable from the vendor. By locating with it the spots where the magnetic attraction is locally above normal surface exploration could be concentrated on those places, and much labour and expense avoided.

Gold

MINING CONDITIONS IN THE DISTRICT

Gold has been known for many years to occur in Rice Lake district, and the area has been rather extensively prospected. In several instances companies carried on considerable underground work and have even erected milling machinery. Nevertheless there is as yet only one producing mine. An important deterrent has been the expense of transportation, which, with the general low-grade character of the deposits, has kept well-established mining companies from locating there. Others, however, less well-advised, have established workings foredoomed to failure by the poverty of the deposits exploited; and in still other instances more or less work has been done by companies as the basis of extensive stock-selling campaigns.

Rice Lake and adjoining districts have already been described by DeLury, who has given detailed and accurate descriptions of the veins on all the more important claims, and readers who desire such information are referred to his work. The present writer will confine himself to a general statement of the methods of occurrence and the origin of the gold deposits.

GOLD VEINS AND THEIR ORIGIN

Gold deposits are found in three general positions; in the later granite, in the earlier granite, and in the Rice Lake series. They were at first found in the Rice Lake series. Afterwards, some deposits were found in the later granite; and later, veins of considerable size were located in the earlier granite, to the north of Wanipigow river and lake. The deposits in the Rice Lake series and the earlier granite are found entirely in the shear zones, or belts of schist, that were formed as a result of the faulting of these rocks. Their maximum size is, therefore, limited by the size of these zones.

Veins in the Later Granite

The deposits in the later granite consist of auriferous quartz filling cracks formed by jointing and faulting. Most of the joints so filled appear to be of the last set formed, with a strike north of 50 degrees west. The veins of this type are, naturally, all small, at least so far as present discovery has shown. The largest seen by the writer is that on the Pendennis claim, a lens some 200 to 300 feet in length, and about a foot wide on the surface. The width is said to increase downward to about 4 feet at a depth of 40 feet. Most of the other veins seen by the writer in the later granite are 3 or 4 inches wide at most.

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Veins in the Rice Lake Series

The veins in the Rice Lake series exhibit some interesting and important areal relationships. In the first place, those of importance occur, with one exception, in the shear zones that strike predominantly northward, that is, away from the granite contact to the south; rather than in those with a more westerly strike, that are approximately parallel to the granite contact. The exception noted is the Wolf vein, near Red Rice lake (claim No. L. 83-124), a large vein with good reported values; and it is to be noted that it lies close to a small outcrop of later granite, which may be the top of a larger body beneath.

When one of the large shear zones is traced throughout its length, another strikingly important fact becomes evident. At the end nearest to the later granite the shear zone is well filled with quartz, that replaces a great part of the schistose rock. At increasing distances from the later granite the amount of quartz in the sheared zone gradually decreases and finally disappears, leaving a sheared zone of country rock. The transition from quartz-filled to quartzless shear zones was traced in each of the large shear zones examined and the conclusion is inevitable, that the solutions carrying and depositing the quartz originated in the later granite.

The distance to which these solutions travelled along the shear zone and deposited quartz presumably varied with the ease of penetration, the volume of solutions available, and the pressure behind them. In the cases investigated the greater part of the deposition ceased within a mile and a half of the contacts; except the most eastern shear zone mapped (which also happens to be the largest in the area) where lenses of quartz 2 to 4 feet in width are found 2½ miles from the later granite.

Quartz is the principal vein mineral. Associated with it are certain sulphides, principally iron pyrites, with small amounts of chalcopyrite, and occasionally a little galena and sphalerite. Non-metallic minerals include albite, iron-bearing carbonate (ankerite or siderite), a little calcite, and in places a little mica and tourmaline. Gold, usually in the free state, is the principal economic constituent.

The minerals mentioned, with the exception of the free gold, crystallized with the massive quartz, indicating that they were all deposited from the same solutions at the same time. In addition to filling the veins, there was a certain amount of replacement of the adjoining schist by the vein minerals, particularly by the sulphides.

Variations in Composition

The mineral composition of the veins exhibits an interesting variation that also indicates the solutions to have originated from the later granite. The veins in the later granite itself are characteristically composed of quartz containing more or less albite. Hand specimens were taken from such veins which consist almost entirely of fine-grained albite. The veins contain rather large proportions of sulphides, and, it is reported, rather high values in gold, up to $50 per ton or even more.

Just outside the later granite the veins consist wholly of quartz, without albite or iron carbonate, so far as observed. They contain moderate amounts of pyrite, although less than the veins in the granite, and are reported to carry gold values in the neighbourhood of $10 to $12 a ton. Iron carbonate begins to appear in the veins, with the quartz, at distances of about a mile from the granite contact. Within this distance the proportion of sulphides diminishes with increasing distance from the granite, and presumably the gold values also, although very little information is available on the subject.

The iron carbonate is first to be observed in the schist near the veins, and in thin offshoots from the veins, rather than in the main veins themselves. With increasing distances from the granite it invades the main veins, and rapidly displaces the quartz. Finally quartz disappears entirely, and the vein material consists almost wholly of iron carbonate. In the most eastern shear zone mapped, this substitution occurs 2¾ miles from the point where the shear zone is cut off by the later granite.

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These changes in composition are due to the changes in concentration and temperature undergone by the solutions while passing away from the granite. While still within the granite they must have been very hot and concentrated, carrying the constituents of albite as well as quartz and sulphides, and depositing them on slight cooling. All the albite constituent was deposited by the cooling of the solution as it entered the cold rocks beyond the granite, and consequently quartz is the chief constituent of these veins. With increasing distance from the granite, the solutions would become still cooler and less concentrated through the deposition of their quartz, until finally conditions were favourable for the deposition of the last constituent, iron carbonate.

Values

In Rice Lake district the sulphides do not apparently carry important values in gold and the values of the veins appear mainly due to their free gold content. The free gold, where observed, forms leaflets along minute cracks or fissures in the quartz, and, therefore, is of slightly later age—presumably deposited by the last remnants of the magmatic solutions, after the earlier quartz had been shattered by slight movement. The quartz is nearly or quite barren of values where it has not been so shattered, but remains hard and vitreous.

In the district north of Wanipigow (Hole) lake, however, the sulphides form a much larger proportion of the veins than in Rice Lake area, and also appear to carry the principal gold values, although free gold is also prominent in some of the deposits.

It may be added that information regarding values was difficult to obtain, and not wholly reliable. Many of the deposits have not been worked for some years past, and several of these are the ones concerning which information is most desirable. The Gold Pan, Gold Seal, and Pan Extension properties, which were active at the time of the writer's visit, are mainly free gold properties, without important concentrations of sulphides.

It may be conceived, however, that since the free gold was deposited from later solutions that seeped through small fissures in the quartz of the veins, the movement of such solutions would be brought to a standstill not far from the edge of the later granite; and the solutions would not get as far away from the earlier granite as did the quartz-bearing solutions. Even if penetration to equal distances did take place, the solutions might have deposited the great part of their load of gold within a short distance from the granite. The meagre facts at hand seem to support the supposition. In two of the shear zones the higher values are comparatively close to the granite, whereas the parts farther away carry lower values.

Shape of Veins

The size and shape of the bodies of vein material in the shear zones depend very largely on the shape of the shear zone itself. Therefore, the extreme variations in size that the shear zones exhibit (page 31) are an important factor in vein formation, and affect seriously the mining value. The quartz veins, like the shear zones, are not regular in shape, but form a series of lenses placed end to end. Sometimes the lenses are connected by a fairly wide neck of quartz, but in many other instances there may be only a narrow stringer of quartz joining them, or none at all. The more continuous veins, naturally, lie nearest their source, the later granite. The veins have the same lenticular shape in depth as on the surface. Even where the shear zone is not lenticular, the bodies of quartz in it are apt to be. This is more particularly the case at some distance from the later granite.

Enrichment from Other Bodies of Granite

Besides the large body of the later granite on the south side of Rice Lake area, smaller granite bodies lying within the Rice Lake series seem to have caused deposi-

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tion of quartz, gold, and sulphides in the shear zones. Thus, on the Wolf claim, L. 83-124, enrichment is greatest at the western outcrop, and decreases rapidly eastward; and about a quarter of a mile to the west, across an area largely drift-covered, a large dyke-like body of the later granite outcrops. Again, a large dyke of granite outcrops in a swamp a little north of the south boundary of the Gold Pan Fractional claim, L. 20-174. As this dyke has an east-west strike it probably runs west into the Mildred claim, L. 35-124. On the north side of the Mildred claim is an outcrop of a strong vein of quartz—said to carry fair values—that runs north about a quarter mile, where it splits into discontinuous lenses and dies out. On the south side of the Gold Pan Fractional claim a narrow, rather discontinuous vein outcrops, exhibiting in places rich samples of gold; and at the contact of this vein with a dyke of later diabase, on the Gold Pan claim, L. 18-174, there is a rich concentration of free gold. The dyke, although fractured by later movement along the fault plane, acted probably as a partial dam to solutions flowing along the sheared zone from the granite dyke; so that cooling and deposition were favoured at the junction.

Detailed Descriptions

It may prove of some value to describe the mining claims as they occur on the various shear zones of which they form parts.

The easternmost shear zone examined is one of the largest in the area. It meets the contact of the Rice Lake series and the later granite on the Moose claim, L. 10-174, and runs northwesterly through the Bluebell, Saxton, Golden Vein, Sunlight, Roland, and Nevada claims successively. On the north side of the Nevada claim it passes into a large swamp, three-quarters of a mile wide. The north side of the swamp is thoroughly burned over, and is now all bare rock. This was carefully examined, and a number of shear zones were observed. Only one of these is at all comparable in size to the great shear zone on the south, the others being only about one-tenth the size. As the large sheared zone is also aligned with the Nevada shear zone, the two are presumably parts of the same zone. The shear zone thus picked up is first seen near the northern side of the Snowstorm claim, L. 62-124. It continues north into the Ranger claim, L. 22-124, and the Golden Rod claim, on the north side of which it swings somewhat to the west and becomes a part of the great shear zone along the south side of Rice lake.

On the Moose claim and northward the shear zone has an average strike of north 28 degrees west, although locally this varies between north 10 degrees west and north 45 degrees west. The shear zone maintains a definite strike as a rule over lengths of 3 to 10 chains only, at the end of which a change in strike occurs. This results in great variation in the width. The straight parts are generally narrow—in one place only 2 feet—whereas the bends widen to as much as 36 feet. There is a good deal of fairly well mineralized quartz, the width of which varies with that of the shear zone, from 9 feet, in the wider shears, down to no quartz at all in the narrower parts.

From the bottom of a shaft said to be 100 feet deep, on the Moose claim, L. 10-174, about 180 feet has been drifted. To the north of the shaft several prospect pits, and a shallower shaft, now filled with water, have been put down.

To the north the shear zone gradually widens, perhaps because it traverses less resistant rock, and on the Nevada claim, L. 27-174, it consists of two sheared belts, 20 and 8 feet wide, separated by about 60 feet of slightly sheared rock. The amount of quartz in the zone diminishes, until on the Nevada claim it forms only discontinuous lenses up to 6 feet wide.

The shear zone is overlain by swamp on the north side of the Nevada claim, but what is probably the same zone reappears on the north side of the Snowstorm claim, L. 62-124. Here it is somewhat wider, varying from 6 feet in straight parts to 50 feet on bends. Very little quartz is to be observed, although on the Ranger claim, L. 22-124, there are a few short lenses of quartz and iron carbonate, 2 or 3 feet wide.

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To the north of the Ranger claim almost no quartz is to be seen. At the boundary between the Ranger claim and the Golden Rod claim, L. 23-124, the vein fillings consist almost wholly of iron carbonate. About 10 chains to the north of the Golden Rod claim the shear zone suddenly widens to 5 or 6 chains, and the strike swings westward. No vein-filling is present. The sheared zone maintains this width for several miles along the south side of Rice lake.

A second wide and important shear zone has its south end in the Lucky Strike claim, L. 52-124. South of the middle of the claim the sheared material has been intruded and replaced by a large diabase dyke that enters it at the north end of the claim. The sheared zone runs northward through the Jumbo and Pilot claims, L. 24-174 and 23-174 respectively, to a point 8 chains west of the northwest corner of the Golden Rod claim, L. 23-124. Here it turns sharply westward, parallels the shear zone last described for about a mile, then turns north again and joins it near the mouth of the creek that drains Red Rice lake.

At its south end in L. 52-124, the shear zone contains considerable quantities of quartz. The source of the quartz may be the large body of earlier granite to the south, but in view of the choking of the shear zone by the diabase dyke, it seems more probably to have originated from two large dykes of granite that cut into the shear zone near the north boundary of the claim. Near the northern boundary of L. 52-124 the sheared zone has a maximum width of 25 feet, which decreases to 1 or 2 feet at the ends of lenses. There is a maximum width of 10 to 12 feet of quartz in the shear zone here, but the average width is not more than half as much. To the north the quartz decreases slightly in amount, but maintains widths of 3 to 5 feet, on the average, in the larger parts of the lenses, almost to the northern boundary of the Pilot claim, L. 23-174. On the Pilot claim there are important amounts of iron-bearing carbonates mixed with the quartz. To the north of the Pilot the shear zone attains widths of 60 feet or more, resembling in this respect the shear zone previously described. The quartz vein-filling rapidly disappears, however, and very little is to be seen north of the Pilot claim.

The third shear zone to be traced outcrops first on the north side of the Mildred, L. 35-124, and runs northwesterly through the Josephine, L. 36-124. The south side of the shear zone is covered by a wide swamp, beyond which the shear zone could not be identified. This zone is characterized by a strong and continuous vein of quartz, 12 feet wide at its southern end, and traceable northward for about a quarter mile, where it begins to assume the lenticular shapes characteristic of the other veins of the region. Almost no quartz is to be seen north of the north boundary of the Josephine. The shear zone itself is rather a zone of fracture than one of strong shear. Very little schist is found on the sides of the quartz vein; and after the vein-filling disappears, north of the Josephine, the shear zone becomes only a vaguely defined zone of fracture, traceable only with great difficulty. It is supposed to be an offshoot of the strong shear zone to the east, splitting off from it at the bend near the north boundary of L. 62-124.

The fourth shear zone traced is that on which the Gold Seal, Gold Pan, and Gold Pan Fractional claims are located, respectively numbered L. 19-174, L. 18-174, and L. 20-174. In the south part of L. 20-174 the shear zone runs into a large swamp, across which it could not be traced. In the swamp, about 6 chains north of the south boundary of L. 20-174, is a dyke of granite with an east-west strike which is supposed to be the source of the vein material filling the shear zone. The zone has an average width of 3 feet or less and, as usual, the quartz is still narrower, averaging less than a foot for the whole zone, and rarely exceeding 3 feet at any point. The zone extends somewhat east of south to the middle of the Gold Seal, where it joins a shear of similar size which strikes off to the east. The two evidently form the sides of a small fault block.

Although small, this shear zone has attracted public attention owing to the rich specimens of free gold obtained from it. Their discovery led to considerable under-

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ground prospecting; for a description of which the reader is referred to DeLury's report. The underground work has emphasized the irregular nature of the mineralization; rich specimens of ore alternate with bodies of barren quartz. The results, so far, raise doubts as to whether mining on the lode will ever be profitable, except perhaps on the Gold Pan which is being worked by the Canada Mining and Leasing Company on a small scale, and at a moderate profit. The main shaft is located on the intersection of the shear zone and a diabase dyke, 20 to 30 feet wide, that has been fractured by the later movements along the shear zone, so that its east side is shifted about 25 feet southward. On the broken face of the western part of the dyke there has been a precipitation of free gold, so rich it is said, that in the first discovery plates of gold as thick as the finger were found. Although nothing approaching this has been recently found, the quartz is still exceedingly rich, specimens seen by the writer being literally bound together with wires and leaves of the precious metal. The disadvantage of the deposit lies in its smallness, confined as it is in length to the single face of the dyke, 25 or 30 feet in length, and in width to the width of the shear zone. The ore-body is, in effect, an almost vertical pipe.

This extraordinary concentration is not, apparently, due to the action of the dyke rock in precipitating gold from the ore-bearing solutions, for the dyke rock in the shaft is hard, glassy, and unaltered. The dyke magma itself did not originate the solutions, as the dyke was intruded, hardened, and faulted before the formation of the ore. The only possible conclusion is, as suggested on a previous page, that the dyke, cutting partly across the sheared zone, acted as an imperfect dam against the movement of the ore-bearing solutions; so that deposition was favoured at this particular point. Deposition on the broken face of the western arm of the dyke rather than on the face of the eastern arm to the south, would indicate, if this theory be correct, that the solutions were moving southward through the shear zone; a conclusion already inferred from the occurrence of the granite dyke on the north and the lack of any other body of granite cutting the shear zone on the south.

The fifth shear zone that was traced outcrops on the west side of the Wolf claim, L. 83-124, east of Red Rice lake. It appears first on the west side of a large hill, and runs down on the west into a low clay-covered area. On the hillside there is about 15 feet of quartz, well mineralized with pyrite, chalcopyrite, and ankerite. Assays of more than 1¼ tons of this ore, made by the Department of Mines, Ottawa, gave values of 1·07 ounces gold, 1·50 ounces silver, and 1·43 per cent copper. The vein and shear zone are traceable for only about 150 feet eastward, after which the shear becomes too small to follow.

Other shear zones in this vicinity are indicated on the map. Nearly all are characterized by quartz in considerable amount at their western ends, although in all except the one described the quartz appears to be barren or poorly mineralized. In all the quartz filling gradually decreases and finally disappears toward the east. These facts suggest strongly that the source of the vein materials for this set of shear zones was the small body of granite southeast of Red Rice lake.

SUMMARY

The gold deposits of Rice Lake district are vein fillings and replacements in belts of schist formed by earlier faulting. The principal veins are found in shear zones that cut through the older rocks to contacts with the later granite, rather than in shear zones that do not so terminate. The veins gradually decrease in size with increasing distance from the granite contact; and their composition varies in such a way as to indicate deposition from hot concentrated solutions in and close to the granite, and from cool dilute solutions at a distance. It is, therefore, concluded that the vein materials were deposited from solutions emanating from the later granite.

The shear zones are found in the Rice Lake series and the earlier granite. The later granite also was jointed, and the joints were filled with auriferous quartz. Such veins are mostly small, although lenses 3 to 4 feet in width have been found.

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Prospecting in the later granite, therefore, although probably less apt to be rewarded than in the older formations, may reveal the presence of small deposits of fairly rich ore.

The vein materials are principally quartz, albite, iron carbonate, pyrite, chalcopyrite, and free gold. The carbonate is characteristically deposited at a distance from the granite, the quartz closer to it, the albite in or very close to it. The sulphides may or may not carry gold values.

The free gold appears, in most cases at least, to have been deposited in the quartz after it was shattered by movement. In great part it seems to have been deposited fairly close to the later granite, although found in small quantities at quite considerable distances away.

The bodies of quartz, like the shear zones in which they occur, vary greatly in width from place to place, forming lenses both in horizontal and vertical section. Small bodies of the later granite may have formed enriched veins like the larger bodies, but the veins so formed are commonly rather short.

Apparently, therefore, the most favourable localities for prospecting lie in the Rice Lake series or the earlier granite, near a contact with the later granite. The earlier granite may be recognized by the belts of schist and the basic dykes that cut it. The later granite is not thus cut, although it may be more or less jointed.

GEOLOGIC HISTORY

The geologic history of the Rice Lake and Oiseau River districts may be stated as follows, from the data at hand. The lack of sedimentary formations makes the history of necessity incomplete, but fuller information must be obtained from other areas, where more complete sections are available.

The first recorded event is the outpouring of the great floods of lava that formed the lower volcanic member of the Rice Lake series. The nature or position of the basement on which the lavas were poured is unknown; no trace of such a base was discovered. The lavas in Oiseau River area are mainly basalts, with some dacite, whereas in Rice Lake area andesites predominate, with minor amounts of basalt and rhyolite. The local occurrence of pillow structure indicates that in places the lavas were extruded under water; but the lack of such structures universally may indicate that in great part the lavas were extruded on a land area. If they were, the disturbances of the drainage accompanying extrusion almost certainly produced lakes, in which later flows could produce the pillow structures locally observed.

The deposition of sediments, probably in local lake basins, began with slackening of volcanic activity. At first sedimentation was interrupted locally by small lava flows, resulting in an interbedding of sediments and lavas; but even this extrusive activity died away, and sedimentation went on uninterruptedly. The sediments first laid down were largely ash rocks, mingled with more or less chemical matter deposited from hot waters following the flows; but later they appear to have been formed by normal processes of erosion. They are largely sandy-textured greywackes. There is evidence, in Rice Lake area, that sedimentation was followed by a renewal of volcanic activity; but faulting has so broken up the rocks there that any conclusion should be fortified by evidence from other localities before being deemed definite.

Following the consolidation of the Rice Lake series there was a period of compression, during which the series was thrown into low folds with average dips of about 20 degrees, probably, and an average strike of north 70 degrees to 80 degrees west. The folding was accompanied or closely followed by intrusion of great batholiths of granite. As folding and batholithic intrusion are common only in mountainous areas, it is inferred that the area was mountain-built and raised above the sea. The lack of later sedimentary formations may indicate that it was never there-

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after submerged in Precambrian time; although the possibility also exists that later sediments may have been deposited, but have been entirely eroded away.

Faulting followed granite intrusion, the faults trending from north to north 70 degrees west. In the faults with a northerly strike, the east sides moved south, and in those with a more westerly strike, the north sides moved upward and westward. It is, therefore, inferred that the stresses causing faulting came from the northeast. The westerly faults are thrust faults, and their planes dip to the north. The faults with a northerly strike show by their strise that the movement of their sides was mainly horizontal; hence they, also, were formed by compressive stresses, although their planes are vertical or nearly so.

The faulting broke up the Rice Lake series and the earlier granite into a series of fault blocks, separated from each other by schist zones of varying width. The larger zones attain widths of 300 or 400 feet under suitable conditions, and may be traced for many miles.

Faulting was followed by intrusion of a variety of basic rocks, most of them dykes. They comprise, in order of intrusion, a hornblende porphyry, a feldspar porphyry, a diabase, and a gabbro. The gabbro also formed large sill-like intrusions in the Rice Lake series or along the contacts between the Rice Lake series and the earlier granite. The gabbro of the sills underwent a pronounced gravitative differentiation while cooling, resulting in the formation of rock types of widely different composition, and in the concentration of metallic sulphides at the bottoms of the sills, forming bodies of copper-nickel ores.

The intrusion of the diabase and gabbro was followed by gentle compressive stresses, causing slight further movements along the old fault planes; then came a second period of folding, accompanied or closely followed by widespread intrusion of great batholiths of granite. The same folding, apparently more intense than the first, forced the Rice Lake series and gabbro sills into steeply inclined positions, usually vertical or even considerably overturned. The intrusion of the later granite was followed by more gentle movements caused by compressive strains, which cracked and jointed the granite in several directions, and gave rise to small lateral movements between the blocks so formed.

During its cooling the later granite emitted considerable quantities of aqueous solutions, loaded with silica, carbon dioxide, sulphur, and iron mainly, with minor amounts of gold and copper. These solutions escaped from the granite along the sheared zones in the older rocks. As they came in contact with the colder rocks of the shear zones, they began to deposit their load, forming quartz-gold veins near the granite, grading into veins of iron carbonate at greater distances from it.

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CANADA

DEPARTMENT OF MINES

HON. CHARLES STEWART, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

GEOLOGICAL SURVEY

W. H. COLLINS, DIRECTOR

Summary Report, 1921, Part D

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PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1922

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SUMMARY REPORT, 1921, PART D

AN EXPLORATION NORTH OF THUNDER BAY, ONTARIO

By T. L. Tanton

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INTRODUCTION

The latter part of the field season of 1921 was spent in making a reconnaissance survey of an unsubdivided area which lies west of Dorion township and north of the townships through which the Canadian Pacific and Canadian National railways run in their course along the north shore of Thunder bay in northern Ontario. The results obtained form an important contribution to the geography of a map-sheet which is in course of preparation; in large part they deal with an area which is very difficult of travel and which is shown blank on existing published maps. A description is given here of the new canoe routes into this little known area which were found and surveyed in 1921. The information will eventually be incorporated into a map of the district, but as given here may in the meantime prove sevriceable to prospectors and others interested in the territory to which the route leads.

DESCRIPTION OF ROUTE

The solid rocks of the district and along the route here described are all Precambrian. They are readily subdivisible into an early Precambrian group of complex structure and a late Precambrian succession of little disturbed sediments and associated igneous rocks. The Basement Complex consists of a Schist Complex and granitic Batholithic Intrusives. The Schist Complex consists of two lithologically distinct divisions one of which is composed almost entirely of banded biotite schist and the other of dense, fine-grained chlorite, hornblende and sericite schists, and banded iron formation. Of the younger Precambrian rocks only the Keweenawan sediments and diabase intrusives are well developed. Animikie sediments were not found underlying the Keweenawan to the north of Loon.

From Dorion station an excellent road runs through the agricultural settlement in Dorion township, rising gradually for 6 miles to the old post-Glacial lake floor where it touches Mr. Gambles' farm on lot 14, concession V. From there the route follows Bishop's trail over boulder clay for 1½ miles to a branch road that leads northerly and slopes gradually down for one-half mile to the south bay of Wolf lake.[1]

Wolf lake is a beautiful sheet of water 4 miles long and averaging a quarter of a mile in width; its southern half is bordered by glaciated, bare hummocks and ridges of granite and gneiss which rise from 30 to 50 feet above the water. The outlet is at the eastern extremity where a shallow rapid runs over gravel. Keweenawan sediments in horizontal attitude overlie the granite rocks within a mile of the lake shore on either side.

[1] Shown on Map 1811, Geol. Surv., Can., Sum. Rept., 1919, pt. E.

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On the east shore, nearly opposite the middle of the lake, a great sill of diabase 300 feet thick appears and under it, on the great cliff face, a few feet of Keweenawan limestone can be seen above the lake level. Mesa-shaped remnants of diabase extend away to the east and northeast, and ridges of the same rock extend southwesterly from the opposite shore. The zone trending north 20 degrees east and one-half mile wide, in which the diabase occurs so abundantly, is regarded as a favourable prospecting ground for lead, zinc, copper, and silver minerals, which are commonly associated in veins occupying faults and fissures in rocks of this type.

The northern end of Wolf lake is surrounded by low land, drift-covered and presumably underlain by Keweenawan sediments. From the head of Wolf lake a portage half a mile long leads over almost level boulder clay to a bay on Wigwam lake. Wolf river, between the two lakes, is a broad shallow stream flowing rapidly over boulders.

Wigwam lake occupies a linear basin which, but for the occurrence of a boulder barrier at its outlet, would be a continuation of Wolf lake. The southern half is bordered by low drift-covered shores, but Keweenawan red tuff outcrops as cliffs along the northern half. These cliffs gradually become higher and closer together and at the northern extremity they are 50 feet high. Two large blocks which have fallen from the cliff on the east side of the lake form a prominent land mark on the shore. A small stream, Balsam Brush creek, enters at this point after traversing a short gorge in a series of falls and rapids. A portage 1,000 feet long was cut to a navigable expansion of this stream, but its exploration was discontinued on account of shallow water and obstructing logs. A land traverse indicated that a sand and boulder clay plain extends at least a mile north and northeast from the head of Wigwam lake.

Wolf river enters Wigwam lake midway, on the west shore. The river makes a sharp bend just above its mouth and a tangle of driftwood piled up among the trees nearby indicates that at times of high water it flows directly across the forested, bouldery barrier along the lake shore. A portage of 1,500 feet leads from a point 400 feet northwest of the river mouth to the outlet of Red Rock lake. The trail ascends a gentle sand and boulder slope for 500 feet, and after mounting a low cliff of Keweenawan sandstone follows down its gently dipping surface to Red Rock lake.

The eastern shore of Red Rock lake is composed of low-lying Keweenawan sandstone and drift. On the western shore granite occurs along the southern half. Near the narrows to the north a small area of red tuff rises abruptly 100 feet above the lake. The northern end of the lake consists of an intricate system of shallow channels enclosing shrub-grown marshy areas. The river above the lake meanders through a silt and clay plain which stands 10 feet above river-level. This is the first area of land fit for agriculture encountered since leaving the Dorion farming area. Six hundred feet upstream from the lake there is a fall 7 feet high over a cliff of nearly flat-lying red dolomitic tuff and sandstone; a portage 700 feet long on the right avoids this obstruction.

One mile above the lake there is a shallow rapid and a sharp turn in the main stream; at the bend a large tributary enters from the northwest. The course up the main stream is pursued southwesterly by following a portage on the right, 1½ miles in length, which starts below the rapids and the tributary's junction. Half-way across this portage, one passes from the soil plain to an area of thinly covered Keweenawan sediments. A remarkable view is obtained, near the upper end of the portage, of the river descending in a series of cascades and rapids through a main gorge which has been incised to a depth of 20 feet through horizontally bedded, red, dolomitic tuff. Within the gorge certain irregular areas of rock stand up prominently and divide the river, at periods of low water, into several channels.

No falls or rapids occur for 1½ miles above this long portage; this is the longest stretch of smooth water on Wolf river. Two log jams are passed by portages on the right. In proceeding southerly upstream the area near the river is a plain standing 8 feet above the river and heavily covered with silt. Low hills rise a short distance back from the river and become higher and closer to it as one travels

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upstream until at the 11-chain portage an area of considerable relief is encountered. The river here falls 20 feet, and the portage is on the right over white sandstone. This sandstone is nearly flat-lying and is traversed by a number of open fissures and well-developed rectangular joints. At an abrupt turn in the river about 500 feet above the 11-chain portage the valley crosses what is probably a fault. The outcrops in this vicinity, though abundant, are not disposed in such a way as to render possible a positive interpretation of the solid rock geology. The rock in the bed of the stream at the foot of the long rapids 500 feet west of the abrupt bend is pink granite and pegmatite of the Basement Complex. The banks of the river rise very steeply on either side to a height of 200 feet, and expose the best section of Nipigon sediments which occurs along this route. Lying on the slightly weathered granite there is a basal conglomerate 20 feet thick composed of granite fragments in a sandstone matrix. Above this is a conformable series of flat-lying sediments made up of 100 feet, mostly of sandstone, succeeded by nearly 100 feet of red tuff. The long rapids are passed by a portage along the top of the cliff on the left side of the river. At 1½ miles above the lower end of this portage, the river-level is the same as that of the stratum of red rock which forms the top of the tableland, and it is obvious that in this distance the river makes a descent of approximately 200 feet. The course of the river, from the upper end of the long rapids to the junction of Greenwood creek, is southwesterly for 2 miles, and westerly for 2 miles, and in this part of the route there are five portages as follows: 3,000 feet, on the right; 400 feet, on the left; 900 feet, on the right; 400 feet, on the left; and 40 feet, on the left.

In this locality the country is of low relief and outcrops of granite and Nipigon sediments are equally numerous. No features of economic interest were observed and it is certain that the sediments occur as thin remnants of an horizontal covering over the gently undulating surface of the Basement Complex.

Twelve miles in a straight line west from the north end of Wolf lake, Greenwood creek enters Wolf river as a sluggish stream 20 feet wide and 1 foot deep. It is navigable for 1,300 feet above the confluence and then disappears among boulders. Granite hills rise 60 feet on either side of the valley; the declivity is abrupt on the right and a portage 1,250 feet long starts from the left bank. Upon reaching the highland, a scale of sandstone is found lying on the granite and by following westerly along the relatively smooth surface thus afforded, Wolf river is reached. The new route, which leads to Greenwood lake, branches southward from a point on this portage 750 feet from its lower end, and after traversing 1,000 feet over boulder-strewn, granite hills, reaches navigable water above a large beaver dam.

Greenwood creek is a very small stream during dry seasons and the total length of the numerous portages which occur between its mouth and Greenwood lake is about 2 miles. It occupies a remarkably straight valley and the granite hills and ridges, which are less than 100 feet high near its mouth, gradually increase in going 4 miles southerly, to a height of 700 feet above the stream.

A large diabase dyke occurs on the portage which is 1½ miles above the mouth of the river. With this exception all the rock observed along the creek is granite and pegmatite. The only noteworthy tributaries flowing into Greenwood creek enter from the south and east at three-quarters of a mile, 1 mile, and 2 miles respectively, below Greenwood lake. These are unnavigable, though they occupy deep valleys. An abrupt change in the direction of Greenwood Creek valley from south to southwest, occurs one mile below the lake, but along the projected line of the river's trend to the south there are a number of prominent drainage features which indicate the existence of a rock valley over 20 miles in length trending almost parallel to the west boundaries of Dorion and McTavish townships and approximately 3½ miles west of this line.

Greenwood lake is of the linear type, being nearly 7 miles long, and averaging a quarter of a mile in width. Its outlet is 4½ miles west and one mile north of the northwest corner of Dorion township; its southern extremity is 3 miles west and 1½

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miles north of the southwest corner of Dorion. The main axis of the northern half of the lake trends north 30 degrees west. An exploration was made in this direction 6 miles beyond the lake. Three small lakes which drain northeasterly into Wolf river were traversed and beyond these, over a divide, upper Wolf river was crossed where it comes from the southwest through a hilly, granite country and turns easterly in an area underlain by Keweenawan sediments. At the bend a stream joins from the northwest, and, a short distance above, two streams join from the southeast and south; none of the streams are navigable. From the sudden change in the relief and geology which occurs near the bend it might be inferred that the area to the north of the high granite hills had been downfaulted; and from the alignment of the rock valleys in a direction north 30 degrees west from the northerly end of Greenwood lake it might be inferred that this marks the position of another fault of less magnitude. Further field work will be necessary in order to verify these inferences.

The drift mantle is very thin over the rugged granite and gneiss area which surrounds Greenwood lake. At the southern end, however, there are very large eskers in the rock valleys and these form part of the divide between the tiny tributaries to the lake and the southward-flowing streams at the headwaters of Mackenzie river. The long, straight valleys in this rocky area appear to be due to faults, but the character of the rocks on either side is such as to make a determination of this matter difficult. It is known, however, that the belt of schist complex which trends nearly east from the southern end of the lake does not occur on the western shore along the continuation of this strike; also, a fault has been observed trending parallel to the axis of Greenwood lake, a short distance west of it.

Land traverses were made westerly from several points along Greenwood lake, and the divide between this part of Wolf River system and the southwesterly flowing waters of Current river was located; but no portages were cut. A land traverse southwesterly from the south end of the lake crossed upper Mackenzie waters which were unnavigable where seen.

The portage from the south end of Greenwood lake to White Granite lake is 1½ miles long and runs south 80 degrees east. The rock on the highland crossed by the trail is granite-gneiss cut by numerous quartz veins; greenstone schists occur both to the north and south at a short distance.

White Granite lake, and Shallow lake—which adjoins it on the east—are boggy ponds each about three-quarters of a mile long. The portage between them starts at the east end of White Granite lake and leads southeasterly a quarter of a mile. It crosses a high, narrow ridge of coarse-grained, white, binary granite.

The creek which flows southeasterly from Shallow lake to Mackenzie lake, 2 miles distant, is unnavigable except where ponds have been formed above beaver dams. A belt of banded mica schists and green schists 1½ miles wide is crossed by this creek. Granite occurs on the portage a few hundred feet before Mackenzie lake is reached.

Mackenzie lake occupies the northwest corner of McTavish township, and from here the route south to Loon station on the Canadian Pacific railway is through McTavish township, continuing almost parallel to its western boundary and one mile east of it. From the eastern shore of the southern extension of Mackenzie lake the portage leads easterly for a quarter of a mile, to a trail between Clegg and Twin lakes at a point one mile north of the latter. Twin lake, which is part of the Pearl River system, is a narrow body 1½ miles long. A portage 3,000 feet long leads south-southwest to the northeastern shore of Wideman lake. The next portage is only a quarter of a mile distant, across the east bay, at the outlet of Wideman lake; it leads south 1,300 feet to Anderson lake. This narrow lake permits canoeing for a little over half a mile; from its outlet to Kline point on Loon lake there is a portage 2 miles in length. At one mile south of Anderson lake a trail branches to the southeast and leads to the mouth of the creek which enters the northeastern end of Loon lake. Loon station is on the southern shore of Loon lake, three-quarters of a mile from

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Kline point. The route from Mackenzie lake to Loon lake is through a rugged granite-gneiss area except for the last third of a mile, which is underlain by Keweenawan sandstone. The geology of a small area immediately surrounding Loon lake is very complex; Keweenawan and Animikie sediments overlie a Basement Complex of Keewatin schists, pre-Huronian sediments, and Batholithic Intrusives. These have been intruded by diabase dykes, and sills and faults traverse the whole assemblage.

ECONOMIC GEOLOGY

Very little of the area mapped on this exploratory trip has been prospected, and the following notes are designed to indicate the mineral possibilities with particular reference to the various geological divisions.

Schist Complex. The area underlain by the Schist Complex in southwestern Dorion is small and presents no features which would indicate that it was a promising field in which to prospect for the minerals commonly sought in Keewatin areas, viz., gold and iron. Numerous barren quartz veins were noted in these rocks; and, when small stocks of granite of younger age than the regional granitic gneiss are found to intrude the schists, veins of similar general appearance may be expected to carry gold.

Batholithic Intrusives. The granitic rocks which form the bulk of the highlands that extend 18 miles north of Loon lake are to be regarded as favourable prospecting grounds for veins carrying silver, lead, and zinc, because faults, presumably of post-Keweenawan age, related in trend and position to diabase dykes, occur in this area. Deposits of molybdenite may occur in the pegmatite dykes. Molybdenite occurs as a primary mineral in pegmatite composed essentially of quartz and red feldspar, on the trail along the east side of Anderson lake, concession VIII, lot 5, McTavish township. The pegmatite is for the most part barren, but certain small, irregularly distributed masses of the rock contain sufficient molybdenite to make a one-per-cent ore. The molybdenite is coarsely crystalline and it would be possible to obtain rich ore by hand-cobbing. The distribution of the molybdenite precludes, in the writer's opinion, the possibility of profitable extraction under present market conditions.

The granitic batholiths of northern Ontario have usually been regarded as unpromising areas in which to search for gold, but the geological work so far done is not sufficient to determine the age relations of the various granitic rocks in the Basement Complex, and there is a possibility that younger granite intrusives may occur, around the margins of which in the older gneisses gold-bearing veins may be found.

Animikie Series. Rocks of the Animikie series do not occur on the highlands north of Loon lake, and they are absent under the thin scale of Keweenawan sediments which overlies the granitic rocks on the north. The Animikie rocks are also absent under the marginal Keweenawan sediments, which overlie the granite at the southerly margin of the granitic highlands half a mile north of Loon lake. To the south of Loon lake the Keweenawan sediments are underlain by the Animikie rocks. Both series dip at low angles toward the south-southeast and have been intruded by diabase dykes and sills and the whole assemblage faulted.

The iron ore occurrences near Loon lake are at present the chief objects of interest to those concerned with the development of mineral deposits in the district. The result of this exploration permits of a small contribution to the general study of the Animikie iron deposits in that it is now possible to state that the boundary of the Animikie rocks at Loon lake coincides approximately with the margin of the original basin of Animikie deposition, the deeper part of which lay toward the south. No rocks which could be recognized as having contributed to the formation of the Animikie sediments either in the form of detritus or igneous emanation were encountered in the highland area.

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Keweenawan Sediments. Keweenawan sediments up to 200 feet in thickness occur in nearly horizontal attitude over the greater part of the country lying northeast and south of the granitic highlands which extend 18 miles north of Loon lake and which narrow abruptly about the middle of Dorion township and extend easterly to Granite point. The series consists of conglomerate, sandstone, red volcanic ash, and limestone. At certain localities the different varieties of the fine-grained sediments are suitable for building stone.

The basal conglomerate seen in the valley of Wolf river, in Stirling township, and in the outcrops north of the east end of Loon lake, and in the rock cut one mile west of Loon is remarkable in that the matrix between the pebbles is composed largely of limestone. This is unusual in this member in the area examined to the south. Nothing of commercial value has been found in this peculiar conglomerate, but in Stirling township certain blocks of the limestone-cemented conglomerate were polished by L. H. Cole of the Mines Branch, Department of Mines, who reported on certain building stones in this locality, and were found to carry small specks of argentite. This occurrence of the silver mineral in a conglomerate matrix not associated with a vein is quite unusual.

Faults of late Keweenawan age traverse the Keweenawan sediments, and the mineralized vein material which cements the fault fissures is, apparently, the chief economic feature.

Keweenawan Irruptives. Diabase dykes intrude all the previously-mentioned solid rocks, and there are many sills of diabase in the Animikie and Keweenawan sediments. The mapping of these irruptives in the rugged, forested areas is difficult, and a great deal of traversing has yet to be done before the extent of the various bodies can be delimited.

The extensions of certain of the great diabase dykes shown on Map 1811, Geological Survey, were located at certain points. The exposed diabase irruptives of this region are supposed to be parts of a great igneous body which, in the late stage of its cooling, gave off those metallic constituents that now form part of the vein-material in the faults and fissures of late Keweenawan age. None of the known well-mineralized veins occur within the diabase, although they are, in most cases, near and oriented in relation to diabase intrusives. Prospectors are advised to search for mineralized veins along faults which traverse or border the diabase masses.

Late Keweenawan Veins. For a general note on the mineral character and occurrence of the late Keweenawan veins in this general area reference may be made to the Summary Report of the Geological Survey for 1919. In the course of the exploration, though no prospecting was attempted, several late-Keweenawan veins were observed. Most of these are exposed on the highlands along the route between Loon and Mackenzie lakes; they trend northeasterly and are small and barren except for occasional crystals of galena. It is probable that larger veins occur in the linear topographic depressions which parallel the course of the veins, for example, the valley followed by the stream draining Mackenzie lake.

An interesting vein was discovered at a point 1,200 feet west of the base of a cove on the west side of Greenwood lake and 1½ miles north of its south end. A brecciated fault zone was there found to trend north 10 degrees west across the foliation of the gneiss. The shattered rocks are filled with a cement of quartz and a small amount of galena, and through this, close to the eastern wall, a later fissure had been filled with a vein of coarsely crystalline marcasite averaging 1½ feet in width through the exposed distance of 50 feet. Chemical tests of the marcasite reveal no precious metals or impurities. It is the only vein of this character known in this region, except where the landward extension of Silver Islet vein crosses the "anorthite" dyke.

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INVESTIGATION OF PEAT BOGS IN ONTARIO[1]

By A. Anrep

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INTRODUCTION

Four peat bogs were surveyed during the summer season of 1921, in order to determine the area, depth, and qualities of peat contained in each. This investigation started late in June and was carried on during July, August, September, and part of October. E. M. Casey acted as a field assistant. A total area of 11,089 acres of peat bogs was investigated in Ontario during 1921.

Three of the four bogs surveyed are situated near the cities of Fort William and Port Arthur. These are called here the Arthur, William, and Twin Cities bogs. The fourth bog surveyed is situated near Verona, in Addington and Frontenac counties.

ARTHUR PEAT BOG

This bog is about 9 miles west of Fort William in the township of Paipoonge, Thunder Bay district. It extends in a northeast and southwest direction (*See* Map 1953). The total area is about 1,474 acres.

Of this area 542 acres have a depth of less than 5 feet with an average depth of 3 feet, and 932 acres have a depth of more than 5 feet with an average depth of 7 feet. The volume of peat contained is 2,623,000 cubic yards in an area with a depth of less than 5 feet, and 10,523,000 cubic yards in an area with a depth of more than 5 feet. The bog is rather shallow, but it is free from knolls and the surface is quite level and would make an admirable drying field. Most of the surface is heavily wooded with alders, dwarf spruce, dwarf birch, and poplar. The southwestern side of the bog could not be used as a drying field because it is margined on that side by an abrupt bank. The bog can easily be drained as it is 45 feet above the Kaministikwia river, and the southern end of the bog is only 1,000 feet from the river.

The peat in this bog is fairly well humified and could be manufactured for fuel. The peat is heavily intermixed with roots and stumps, but in most cases these are sufficiently decomposed for a drill to penetrate. Samples show that the peat is composed mainly of carex plants slightly intermixed with sphagnum and eriophorum, the former being the more prevalent.

The bottom is formed of reddish sand intermixed with clay.

[1] All figures in this report are approximate. A ton is considered as 2,000 pounds. A cubic yard of drained bog is assumed to be equal to 200 pounds of dry peat.

In the tables of analyses, figures in column R refer to fuel as received, and in column D to fuel dried at 105°C. The analyses were made on the fuel as received and the other results were calculated therefrom.

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The 542 acres less than 5 feet may be excluded from consideration as a commercial source of peat. Allowing 2 feet for the decrease in depth through drainage, the remaining 932 acres would have an average depth of 5 feet and a total of 7,518,000 cubic yards. The total dry tonnage is 752,000 tons or 1,003,000 tons of peat fuel having 25 per cent of moisture.

Analysis of Peat from the Arthur Peat Bog

Sample	I		II		III	
	R	D	R	D	R	D
Moisture.....%	7·3	.....	9·1	.....	9·0	.....
Ash.....%	13·9	15·0	12·3	13·4	12·5	13·7
Volatile matter.....%	52·8	57·0	52·4	57·7	53·3	58·6
Fixed carbon (by difference).....%	26·0	28·0	26·2	28·8	25·2	27·7
Sulphur.....%	0·4	0·4	0·5	0·6	0·5	0·6
Nitrogen.....%	1·8	1·9	1·6	1·7	1·5	1·6
Calorific value in calories per gram, gross.....	4,160	4,490	3,840	4,230	3,980	4,370
" value in B.Th.U. per lb., gross.....	7,480	8,070	6,920	7,620	7,160	7,860
Fuel ratio, fixed carbon, volatile matter.....	0·49	0·49	0·50	0·50	0·47	0·47

WILLIAM PEAT BOG

This bog is situated near Fort William and Port Arthur, in McIntyre and Neebing townships. It extends in a northeast and southwest direction (*See* Map 1952).

Its total area is 1,789 acres. Of this area 926 acres have a depth of less than 5 feet with an average depth of 3 feet, and 863 acres have a depth of more than 5 feet with an average depth of 7 feet. The volume of the peat contained is 4,482,000 cubic yards in an area less than 5 feet deep and 9,743,000 cubic yards in an area more than 5 feet.

The peat is fairly well humified and could be utilized for the manufacture of machine peat fuel. It is slightly inferior to the peat in the Arthur bog. It is rather shallow, but the surface is free from knolls and is comparatively level and, therefore, suitable as a drying field. The entire surface is heavily wooded with spruce, alders, dwarf birch, and poplar. This bog could be easily drained, as the eastern end is situated 1,000 feet from McIntyre creek and the southern end is about the same distance from Neebing creek, both of which flow with a free current. Stumps and roots were encountered, which do not seem to be as well decomposed as those in the Arthur bog, but they should not amount to a serious hindrance. The peat is mainly composed of carex plants, heavily intermixed near the surface with sphagnum; occasionally, eriophorum is found. Remains of various aquatic plants were visible in the deeper section of the bog.

The bottom is formed of reddish sand intermixed with clay.

The samples were found greatly deficient in cohesive properties. This is due to the frost penetrating almost the entire thickness of peat before snow covered the surface. Such occurrences seem to be characteristic of this part of the country.

Both the Arthur and William bogs are very conveniently situated as regards market. The Arthur bog is traversed both by the Canadian Northern and Canadian Pacific railways and the William bog is situated in the immediate vicinity of the Twin Cities.

Excluding from consideration the 926 acres of bog which is less than 5 feet deep and allowing 2 feet for drainage, there are approximately 863 acres of utilizable peat with an average depth of 5 feet. The total volume is 6,962,000 cubic yards. The total dry tonnage is 696,000 tons or 928,000 tons of peat fuel having 25 per cent of moisture.

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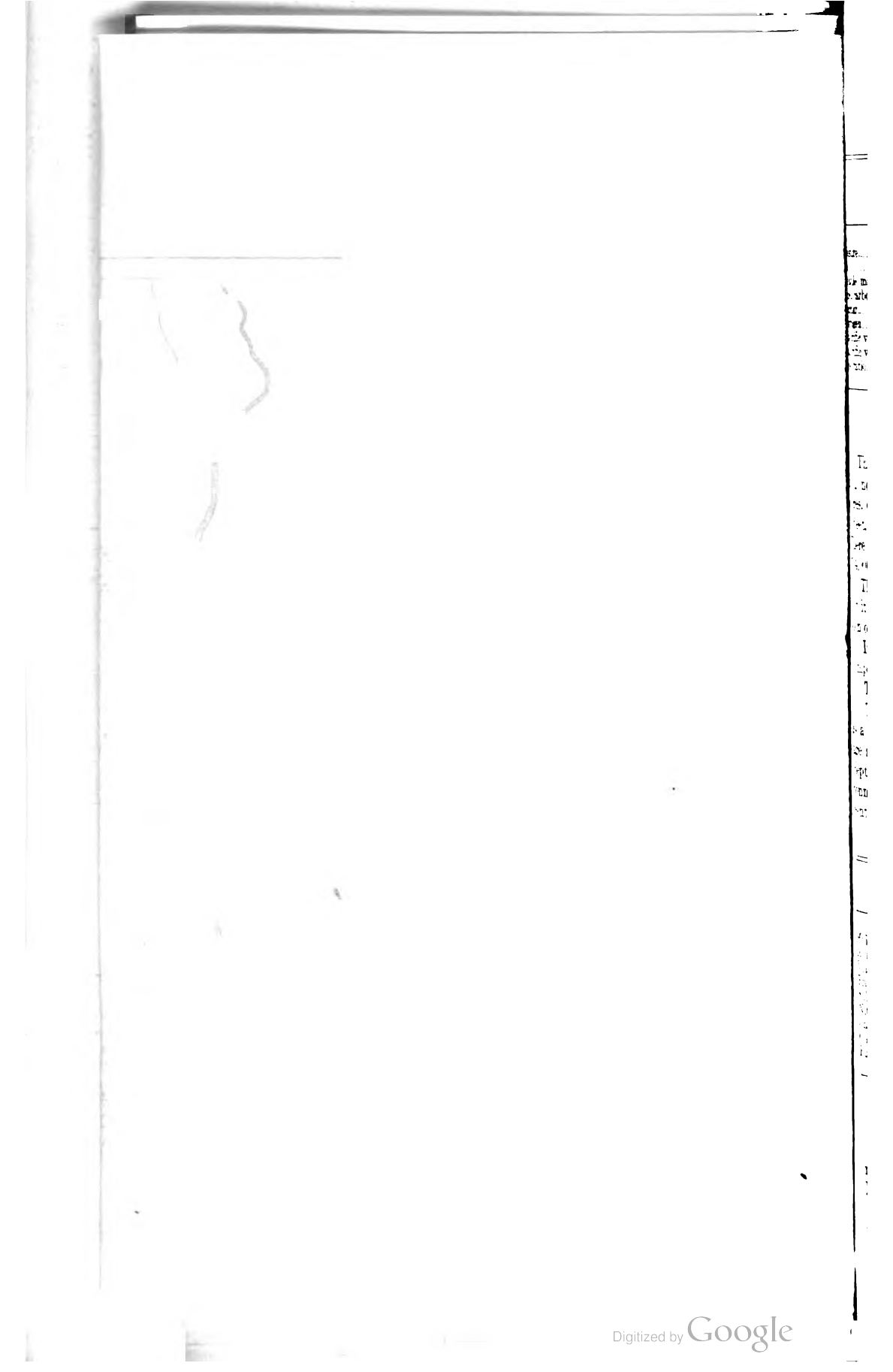
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Analysis of Peat from the William Peat Bog

Sample	I	
	R	D
Moisture..... %	6·2	.....
Ash..... %	10·6	11·3
Volatile matter..... %	59·3	63·2
Fixed carbon (by difference)..... %	23·9	25·5
Sulphur..... %	0·3	0·4
Nitrogen..... %	1·7	1·8
Calorific value in calories per gram, gross.....	4,500	4,800
Calorific value in B. Th. U. per lb., gross.....	8,100	8,630
Fuel ratio, fixed carbon, volatile matter.....	0·41	0·41

TWIN CITIES PEAT BOG

This bog lies within the city limits of Fort William and Port Arthur. It extends in a northeast and southwest direction (*See* Map 1952). The total area is 993 acres, of which 895 acres have a depth of less than 5 feet with an average depth of 3 feet, and 98 acres have a depth of more than 5 feet with an average depth of 5 feet. There are 4,332,000 cubic yards in the area with a depth of less than 5 feet and 794,000 cubic yards in the area with a depth of more than 5 feet.

The peat is fairly well humified and is suitable for fuel. The bog is very shallow but it is already thoroughly drained, as this section has been laid out for the expansion of the Twin Cities and is, therefore, never likely to be worked for peat.

It is almost free from wooded growth and the surface is level. This bog is mostly composed of sphagnum slightly intermixed with carex and eriophorum plants.

The bottom of the bog is formed of reddish sand intermixed with clay.

The 895 acres with a depth of less than 5 feet may be left out of consideration as a source of commercial peat. As the bog is already thoroughly drained no shrinkage allowance for drainage need be made for the remaining 98 acres with an average depth of 5 feet, which have a total volume of 791,000 cubic yards of peat. The total tonnage of dry substance is 79,000 tons, or 105,000 tons of peat fuel having 25 per cent moisture.

Analysis of Peat from the Twin Cities Peat Bog

Sample	I	
	R	D
Moisture..... %	6·7	.....
Ash..... %	8·0	8·6
Volatile matter..... %	58·2	62·4
Fixed carbon (by difference)..... %	27·1	29·0
Sulphur..... %	0·5	0·5
Nitrogen..... %	1·4	1·5
Calorific value in calories per gram, gross.....	4,520	4,850
Calorific value in B. Th. U. per lb., gross.....	8,140	8,730
Fuel ratio, fixed carbon, volatile matter.....	0·46	0·46

VERONA PEAT BOG

The east end of this bog lies south of Verona, the central part is south of Bellrock, and the western part, about one mile south of Enterprise, in Camden East and Portland townships, Addington and Frontenac counties (*See* Map 1951). Its total area is 6,833 acres. Of this area: (a) 1,429 acres have a depth of less than 5 feet with an average depth of 4 feet; (b) 2,121 acres have a depth of from 5 to 10 feet with an average depth of 7 feet; (c) 1,881 acres have a depth of from 10 to 15 feet

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with an average depth of 12 feet; (d) 1,302 acres have a depth of from 15 to 20 feet with an average depth of 16 feet; and (e) 100 acres have a depth of more than 20 feet with an average depth of 20 feet.

The volume of peat contained is approximately:

9,222,000	cubic yards in	(a)
23,963,000	" "	(b)
36,418,000	" "	(c)
33,618,000	" "	(d)
3,230,000	" "	(e)

The bog is deepest between Verona and Bellrock and if the surface there were cleared and the bog properly drained it would be very suitable for fuel. It has the special advantage of long working lines and wide spreading fields. The bog in Camden East township, though shallower, is of satisfactory depth and has good working lines. Both of these sections would be suitable for the manufacturing of peat by any of the present known methods, which require long and wide spreading and drying fields.

The bog south of Verona is divided by Hardwood creek which flows south into Cameron creek. The section between Cameron cut and Hardwood creek drains into Napanee lake which in turn drains down Napanee river. The bog west of Depot river drains into Cameron creek which flows towards Cameron cut. The land rises considerably on either side of the bog so that it lies more or less in a continuous valley.

The surface has been flooded during the greater part of the spring, but since the dam at Cameron cut was removed it has a better chance to dry.

The peat throughout the whole bog is very well humified, has good cohesive properties, and possesses a considerable depth. The peat is composed mainly of carex remains of grasses, dead trees, and shrubs. No sphagnum was encountered and only once a few hypnum plants were noticed. The bottom layers of the bog are composed of aquatic plants below which is a layer of about 2 or 3 feet in depth of greenish gelatinous substance which seemed to be composed of vegetable and diatomaceous siliceous shells, freshwater mollusks, and littoral remains. The greater part of the peat is thickly intermixed with roots, logs, and stumps. The bog is very heavily wooded with ash, soft maple, birch, willows, poplars, alders, and numerous other varieties of deciduous bushes.

The bottom of the bog is a thin layer of blue clay under which stone or sand is encountered.

This bog is very well situated as regards market and shipping facilities, being surrounded by farming districts and small villages and touching at the east end the Canadian Pacific railway and at the west end the Canadian Northern.

Leaving out of consideration the 1,429 acres with a depth of less than 5 feet and allowing 3 feet for the decrease in depth through drainage, there is left:

		Feet
2,121	acres with an average depth of approximately	5
1,881	" " " " " " "	10
1,302	" " " " " " "	14
100	" " " " " " "	18

There is a total volume of 79,768,000 cubic yards of utilizable peat and the total dry tonnage would be 7,977,000 tons or 10,636,000 tons of peat fuel having 25 per cent of moisture.

The drainage of this bog could be effected by blasting and deepening Cameron cut. The clearing and drainage in general would be rather costly, but, on a large scale, the peat could be manufactured on a commercial basis.

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Analysis of Peat from the Verona Peat Bog

Sample	I		II		III		IV	
	R	D	R	D	R	D	R	D
Moisture.....%	9·7	.....	9·3	.....	10·3	.....	11·1	.....
Ash.....%	15·6	17·3	13·4	14·8	12·0	13·3	19·7	22·2
Volatile matter.....%	54·8	60·7	55·9	61·6	55·2	61·6	48·4	54·4
Fixed carbon (by difference).....%	19·9	22·0	21·4	23·6	22·5	25·1	20·8	23·4
Sulphur.....%	2·1	2·3	1·6	1·7	1·4	1·6	1·0	1·1
Nitrogen.....%	2·4	2·7	2·6	2·9	2·8	3·1	2·4	2·7
Calorific value in calories per gram, gross.....	4,130	4,570	4,130	4,550	4,200	4,680	3,780	4,250
Calorific value in B. Th. U. per lb., gross.....	7,430	8,230	7,430	8,180	7,560	8,430	6,800	7,650
Fuel ratio, fixed carbon, volatile matter.....	0·36	0·36	0·38	0·38	0·43	0·43	0·42	0·42

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SYNOPSIS OF INFORMATION CONCERNING THE PEAT SITUATION IN CANADA

By A. Anrep

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Peat is a combustible substance formed from vegetable matter by processes of accumulation through ages, and slow decay resulting in various degrees of humification.[1]

The degrees of humification and the quality of peat depend upon: (*a*) the temperature under which the peat was accumulated; (*b*) the kind of vegetation from which it is formed.

Following is a convenient and practical classification of peat based on the degree of humification:

Peat suitable for the manufacture of peat fuel	(A) ( ) (A—)	highly humified; good
	(AB+) ( ) (AB)	well humified
	(AB—) ( ) (B+)	fairly well humified
	(B)	less well humified; poor
	B—	not suitable for the manufacture of peat fuel or peat litter
Peat suitable for the manufacture of peat litter	(BC+) ( ) (BC)	slightly humified; poor
	(BC) ( ) (C+)	fairly free from humus
	(C) ( ) (C—)	almost free from humus; good

Peat in its natural state contains from 87 per cent to 92 per cent of moisture, according to the drainage of the bog. This content of moisture must be reduced to 25 per cent or 30 per cent before the peat can be used as efficient fuel; and to 20 per cent or 22 per cent of moisture to produce good peat litter.

Peat fuel bogs are formed from the following kinds of vegetable matter:

Mosses, especially sphagnum and hypnum.
Carex plants such as rushes, sedges, and grasses.
Scirpus and eriophorum plants such as club-rushes and cotton grasses.
Heath plants, aquatic plants, and trunks and roots, fallen trees and leaves, etc.

Peat litter bogs are former principally from the mosses, especially sphagnum.

Peat bogs are classified according to location and composition as:

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[1]Humification is here used to mean the change of vegetable matter into *humus* or vegetable mould, rendering the soil favourable to forest growth.

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High Bogs: Formed principally of the remains of mosses, eriophorum plants, heath plants, and forest residue. Some of these bogs are shaped like enormous sponges and vary in depth from 3 feet to 30 feet or more towards the middle.

Low Bogs: Formed principally of remains of carex and aquatic plants, which require more nourishment than the plants forming the vegetation of high bogs. Low bogs are found chiefly in localities which are occasionally or periodically flooded. The depth varies from 1 foot to 9 feet or slightly more.

PEAT AS FUEL

The greatest difficulty in the economical manufacture of peat fuel is the removal of water. Up to the present the air-dried process has given the best results. This method has been greatly improved by processes that adapt it to weather and labour conditions. The season during which peat can be manufactured in Canada is very short, varying from 90 to 100 days, but under favourable conditions and with existing improved apparatus the manufacture of peat fuel should prove commercially successful if properly conducted.

The methods employed for the manufacture of air-dried peat fuel are:

Hand-cut peat; raw peat is cut out of the bog by hand and air-dried, without undergoing any mechanical treatment.

Wet or tramp peat; raw peat with water added to it is tramped by horses or men and, when of a proper consistency, is run into moulds in the open to be air-dried.

Machine peat; raw peat is dug mechanically or by hand and elevated into a macerator, where it is subjected to intense maceration. The macerated peat is mechanically transported and spread in the open where it is left to be air-dried.

As soon as the spread peat is sufficiently dry to be handled it is turned and after a few days is cubed, the cubes being piled in beehive-shaped heaps. This is done by hand and when manufactured on a large scale, the harvesting and the loading into railway cars are conducted mechanically.

One and four-fifths tons of machine peat are equal in calorific value to 1 ton of anthracite coal. Peat is, however, much more bulky, having 3·6 to 4 times the volume of anthracite. It is, therefore, more expensive to transport and for this reason the bog should be situated close to transportation and market. If the bog is not favourably located the manufactured peat may be burned in gas producers for the developing of electric energy; for the manufacture of by-products, chiefly ammonium sulphate; or it may be coked or converted into powder.

GENERAL USES OF PEAT

Peat is a good fuel for grates, cooking stoves, and Quebec heaters. It is very clean to handle and can be easily ignited; it burns with a long yellow flame and leaves as a rule a small deposit of yellow or red powdery ash free from clinkers.

Peat is well adapted for use in furnaces during the early spring and late autumn when a short, quick fire is desired; during the winter months it should be mixed with coal when the fire burns low. Our winters are too severe for peat to be used by itself in ordinary furnaces.

Peat has also been satisfactorily used under boilers, but it requires a great deal of stoking and feeding.

Peat litter is manufactured entirely from sphagnum mosses, which are almost free from humus. The raw peat is dug out with spades in brick form during the autumn months, spread out on the surface of the bog, and left to freeze until the following spring. After it has been air-dried it is brought to the plant and passed through a tearing machine. During this process a certain amount of "mull" is formed. The product from the disintegrator passes through a sieve and the two products are separated, and afterwards pressed separately into bales.

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Peat litter having great absorption qualities and being a natural cleanser, is extensively used in northern Europe as bedding for horses, cattle, and other barnyard animals, except sheep. It can also be used as an absorbent and packing for surgical dressings, as absorption pads for sanitary purposes, for the manufacture of paper and alcohol, and, mixed with molasses, as food for fattening cattle.

MANUFACTURE OF PEAT FUEL IN CANADA

Millions of dollars of public money have been unprofitably spent in Europe, United States, and Canada in testing inventions for manufacturing artificially dried peat fuel. In 1918, a joint Peat Committee was appointed by the Governments of Canada and Ontario to promote the peat industry in Canada by experimenting with and developing the most suitable and successful of air-drying devices. After careful investigations the air-dried process was adopted, and in 1919 the committee erected two improved plants on the Alfred peat bog, near Alfred, Prescott county, Ontario, on the Ottawa-Montreal short line, of the Canadian Pacific railway, 42 miles from Ottawa, to obtain accurate data as to the best plant for use in this country.

A small quantity of briquetted peat is also manufactured by Le Combustible National Limitée at Ste. Therese de Blainville, Que., 20 miles northwest of Montreal. No detailed information is available in reference to the practice followed.

FALLACIES IN REGARD TO DRYING PEAT

Artificial Drying. Many attempts have been made to devise a substitute for air drying but so far they have not been successful. A short comparison of a few of the best known systems is given below.

(*a*) By putting the peat through an artificially heated dryer, through which a strong current of air is driven, thus imitating the natural process of air drying:

A very well drained bog contains on an average 85 per cent moisture, but often a little more. If such a bog be rendered absolutely dry, the product would have a calorific value of 1·8 B.T.U. per pound or 5,400 calories. A drier constructed to utilize 80 per cent of the calorific value of its fuel—if such a drier could be constructed—would require, to evaporate the water from 100 pounds of peat, a consumption represented by the formula,

$$\frac{85 \text{ (per cent of moisture)} \times 640 \text{ (degrees latent heat)}}{0{\cdot}8 \text{ (per cent efficiency)} \times 5{,}400 \text{ (calories of heat per gram of peat)}} =$$

12·4 pounds of dry peat, and the yield would be 15 pounds of dry peat. Even under such nearly ideal conditions, therefore, 100 pounds of wet peat would produce only 2½ pounds of perfectly dry peat.

(*b*) By treating the peat in a vacuum apparatus. If a vacuum apparatus could be constructed capable of vapourizing about 25 pounds of water for every pound of dry peat consumed by it, having a calorific value of 5,400 calories, then from the 12·5 pounds of peat substance contained in 100 pounds of peat pulp having 87·5 per cent of moisture there would be obtained $12{\cdot}5 - \frac{87{\cdot}5}{25}$ or 9 pounds of dry peat, that is, 72 per cent. This would be quite satisfactory, but no such efficient apparatus has been invented; and even if there were such a machine it would be too expensive to operate profitably.

(*c*) Attempts have also been made to remove mechanically, by means of filters, presses, and centrifugal pumps, so much water from the peat that the remaining water could be economically expelled by artificial heat. In rare instances it has been feasible with certain kinds of peat pulp to reduce the water content in this manner

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to 65 per cent, but in the majority of cases a reduction to 70 per cent is difficult to obtain. Even if a press could reduce the moisture content to 70 per cent, the cost of fuel for artificial drying would still be too great. For instance, 100 pounds of peat with 70 per cent moisture would require (as in previous calculations) 11 pounds of dry peat for heating the drier. In addition allowance would have to be made for working expenses or depreciation, and for the fuel consumption for mechanical power. Of the 30 pounds of peat substance produced at least half would be consumed in the operation. The centrifugal method for reducing the water content of ordinary peat is even less effective than pressing. Of course if peat so treated contains 70 per cent of moisture and could be dried in a vacuum apparatus, a net output would be available of $30 - \frac{87.5}{25} = 26.5$ pounds, or 88 per cent of the fuel content of the original peat. This would be a satisfactory result, but as before mentioned not only would it be difficult to bring down the water content to 70 per cent, but no vacuum apparatus of sufficient capacity has been invented.

Peat is composed of gelatinous matter and because of its gelatinous consistency it is difficult to remove the water from peat pulp. It is comparable in this respect to gelatinous silica and alumina. When pulped peat is treated in a filter press a thin layer of gelatinous peat gathers on the surface of the canvas, preventing the water from passing through. If the best humified peat is squeezed in the hand it will be found that the peat squeezes through the fingers, without losing a drop of water.

Experiments have also been carried on with the so-called osmotic method to have the raw peat submitted to mechanical pressure and simultaneously traversed by an electric current parallel to the direction of the pressure which tends to send the water towards the cathode. This method is supposed to destroy the peat cells and render the water more easily expressible from the peat. However, it has been proved that well humified peat is not cellular; for the reason that the vegetable cells of the original plant matter are destroyed by humification.

(*d*) A great deal of money has been spent upon the wet-carbonized system. The raw peat pulp is treated under pressure, to a temperature of 150° C. and even higher, during which time the peat undergoes a two-fold change.

(1) It loses its gelatinous character and becomes amorphous, thus permitting the water to be more readily separated.

(2) It becomes coked or "wet-carbonized" the completeness of which process depends on the temperature used.

Even this system so far has not proved economical and very little has been heard of it during recent years.

AREA OF PEAT LANDS INVESTIGATED IN CANADA

According to R. Chalmers' report on peat,[1] there are in Canada approximately 37,000 square miles of bogs. Since May, 1908, a systematic investigation of the peat bogs has been carried on during the summer months, but only a fraction of this area has been examined.

In Ontario forty-six bogs have been surveyed. These have a total area of 123,321 acres and contain approximately 110,109,000 short tons of peat fuel containing 25 per cent of moisture and 518,000 tons of peat litter containing 20 per cent of moisture.

In Quebec twenty-three bogs with a total area of 76,649 acres have been surveyed. These contain approximately 70,458,000 tons of peat fuel containing 25 per cent moisture and 6,890,000 tons of peat litter containing 20 per cent moisture.

In New Brunswick thirteen bogs have been surveyed. These have a total area of 3,604 acres and contain 499,000 tons of peat fuel (approximately) containing 25 per cent moisture and 2,268,000 tons of peat litter containing 20 per cent moisture.

[1] Chalmers, R., Mineral Resources of Canada, Bull. on Peat. Geol. Surv., Can., 1904.

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In Nova Scotia eight bogs have been surveyed. These have a total area of 8,671 acres containing approximately 6,188,000 tons of peat fuel containing 25 per cent moisture, and 453,000 tons of peat litter containing 20 per cent moisture.

In Prince Edward Island six bogs have been surveyed. These have a total area of 5,356 acres containing 1,213,000 tons of peat fuel (approximately) containing 25 per cent moisture, and 1,160,000 tons of peat litter containing 20 per cent moisture.

In Manitoba nine bogs have been surveyed. These have a total area of 6,530 acres containing approximately 1,863,170 tons of peat fuel containing 25 per cent moisture, and 2,553,110 tons of peat litter containing 20 per cent moisture.

Reconnaissance survey has also been made of some large bogs in Manitoba, which aggregate approximately 236,000 acres.

A total of one hundred and five bogs have been fully surveyed with an aggregate area of approximately 224,131 acres. These contain 190,330,170 tons of fuel and 20,588,110 tons of litter containing 20 per cent moisture.

Total reconnaissance survey: number, 9; approximately 236,000 acres.

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GOUDREAU GOLD AREA, MICHIPICOTEN DISTRICT, ONTARIO

By Ellis Thomson

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INTRODUCTION

Gold was discovered in this district in 1918, but was at that time considered as of minor importance compared with the pyrite deposits, both because of the smallness of the gold-bearing veins and because of war-demand for pyrite. It was not until the discovery of gold in the Murphy property, township 28, range XXVI, in the spring of 1921, that the district attained any prominence as a possible gold producer.

During the summer of 1921 the district to the east and west of Goudreau was visited by A. G. Burrows of the Ontario Bureau of Mines who made a brief but timely official report[1] on the principal properties.

During the field season of 1921 the writer was given very able assistance by W. F. James and S. H. Davis. Only the former, however, was with him during the examination of the gold properties in the Goudreau district. The writer cannot speak too highly of the assistance rendered by him in that connexion, particularly in working out the detailed geology of claim 408 on Murphy lake.

The writer wishes also to acknowledge the kindness and co-operation of the various residents of Goudreau, whose names are too numerous to mention separately, the hospitality and help extended by Messrs. Brighton, Cline, Webb, and Daimpré, and the very kind assistance rendered by officials of the Algoma Central railway.

LOCATION

The gold-bearing area (Figure 1) is near Goudreau station, on the Algoma Central and Hudson Bay railway, 177 miles north of Sault Ste. Marie and about 17 miles south of Franz, the junction-point of the Algoma Central railway and the Canadian Pacific railway. Gold has been found on both sides of the railway, the older discoveries lying to the east, the newer ones to the west, of the right-of-way. The more important claims may be reached either by canoe route or by wagon road, and are included for the most part in township 28, range XXVI, township 27, range XXVII, and township 26, range XXVII, Algoma district.

TOPOGRAPHY

The contour of this comparatively small area is of the same character as in the rest of the Michipicoten district. Undulating rocky country alternates with marshy ground, and the district is studded with lakes and streams. Most of the water to

[1] Burrows, A. G., Can. Min. Jour., vol. XLII, No. 31, Aug. 5, 1921.

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the west of Goudreau drains west into Magpie river; the streams and lakes to the east of Goudreau drain south and east into Michipicoten river. The country on either side of the Algoma Central railway has been burnt over at least once, and in several instances, two or three times, and there is little timber except second-growth poplar and birch.

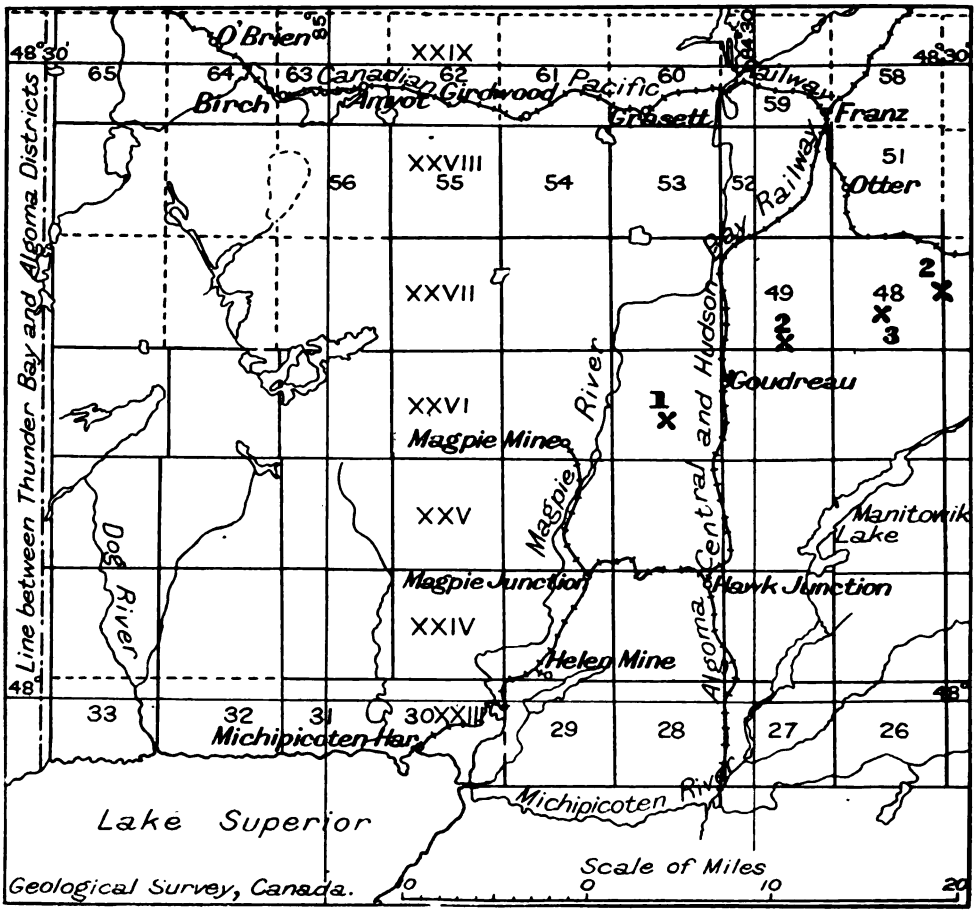

Figure 1. Index map showing location of groups of gold claims in Goudreau area, Algoma district, Ontario. 1, Murphy; 2, McCarthy-Webb; 3, Cline.

GENERAL GEOLOGY

Most of the rocks are acid and basic volumes of the Keewatin formation, but these volcanics have intercalated with them small bands of iron formation and are intruded by a boss of granite. All three of these formations are cut by the diabase dykes of probable Keweenawan age which are so prevalent in this region. The dykes are, in general, younger than the gold ore deposits, the veins being faulted by them in several places. The geological succession is briefly as follows:

Pleistocene deposits of boulder clay, sand, and other loose deposits
Diabase dykes of probable Keweenawan age
Granite
Iron formation
Keewatin volcanics (both acid and basic)

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PLEISTOCENE

The Pleistocene deposits are for the most part sand and gravel with smaller amounts of boulder clay. Numerous large boulders suggest old beaches or terraces of lake Superior or its predecessor. Evidence of ice action is not so common here as in some localities, but occasional striæ and morainic material may be observed.

DIABASE DYKES

The diabase dykes are of two distinct types. The first—the younger—usually contains olivine; the second is an older quartz diabase. Both types have already been described[1] in detail, and it is only necessary to add that—as with the pyrite deposits—the gold veins mostly remain unaffected by the intrusion of the olivine diabase dykes, but are sometimes faulted along the fissures occupied by the quartz diabases. These diabase dykes seem to be more prevalent to the east of the Algoma Central railway than they are to the west.

GRANITE

The only boss of granite observed in this area is in the middle of township 28, range XXVI. It is coarse-grained rock, gneissoid in places, and consists chiefly of quartz, orthoclase, plagioclase, and chlorite, with minor amounts of calcite, limonite, and hornblende. It varies in composition from a fine granite to a granodiorite. Locally it is porphyritic and corresponds to a very coarse quartz porphyry. It is close to the best gold-showing in the district and had apparently some connexion with the deposition of the ore. It weathers very readily, showing a characteristic white surface. It is traversed by numerous acid dykes that vary from pegmatites to quartz veins, the latter in some cases carrying free gold and sulphides. The granite intrudes the Keewatin volcanics, but is older than the diabase dykes.

IRON FORMATION

The iron formation has already been described.[2] It differs from the majority of other iron formations in the predominance of the siderite and pyrite members. The bands of iron formation are confined for the most part to the eastern half of the area (Figure 2), but one or two have also been encountered west of the Algoma Central railway. In some places the rocks of this formation have yielded gold values, but principally it would appear from being traversed by small gold-bearing quartz stringers.

KEEWATIN VOLCANICS

These volcanics form 80 or 90 per cent of the rock outcrops. They comprise volcanic flows of two distinct types, acid and basic, and a few occasional flows of an intermediate composition corresponding to andesites or quartz andesites. West of the Algoma Central railway the basic types predominate, but to the east of the right-of-way the acid flows are the more common. For the most part the acid rocks in this locality are older than the iron formations, whereas most of the basic flows are younger than these. Exceptions to this general rule are to be found, however, older basic flows and younger acid flows being encountered in some places.

Basic. The basic Keewatin rocks have already been described[3] and attention will be confined to individual types in which there are gold-bearing veins. These are for the most part fine-grained volcanics with the original texture and composition of a basalt, but so highly altered that their original composition is difficult or

[1] Collins, W. H., "The Ore Deposits of Goudreau and Magpie-Hawk Areas in Michipicoten District." Geol. Surv., Can., Sum. Rept., 1918, pt. E.
[2] Loc. cit.
[3] Loc. cit.

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impossible to determine. In certain instances, when quartz is present they may more properly be classed as quartz andesites. Under the microscope they appear as highly weathered rocks consisting chiefly of altered plagioclase and hornblende, but containing also considerable secondary carbonate and quartz. The quartz occurs chiefly in the form of small stringers, whereas the carbonate appears both in that form and as an alteration product of the other minerals. The feldspars are largely altered to kaolin, sericite, or carbonate, the hornblende in some cases to chlorite. In the vicinity of veins this rock frequently carries biotite, quartz, muscovite, and occasional needles of tourmaline, as a result of the hydrothermal processes accompanying vein intrusion.

In some places the surficial types, amygdaloids, vesicular lavas, and tuffs are prevalent, and in others the fine-grained volcanics give place locally to a coarse-grained basic rock corresponding to an amphibolite. In some places these rocks become porphyritic and although very highly altered their original porphyrite character may be determined.

Acid. As in the case of the basic volcanics only those acid types in which the gold-bearing veins occur need be described. The quartz porphyry and feldspar porphyry types are the important acid flows in this regard, but a felsitic type also carries some gold-bearing veins. An ottrelite porphyry occurs in small amount. These acid rocks are traversed in places by numerous short stringers carrying gold-bearing quartz. The stringers, or veins, are of two types, one following the schistosity of the rock and the other cutting across it.

Structure. According to Collins[1] the rocks of the Keewatin complex in this district have been folded along an axis pointing 60 degrees east of north; and the intrusion of the older Precambrian diabase dykes was connected wth a milder earth movement which resulted in faults of considerable size. The writer has noted likewise that in connexion with the younger Precambrian diabase dykes there has been some movement resulting in places—notably in the Murphy claims—in the very slight displacement of some of the gold-bearing veins.

ECONOMIC GEOLOGY

GOLD

The gold ore carriers in this district are of three distinct types, two of them much more prevalent than the third. The first type is represented by small quartz veins following the lines of schistosity of the Keewatin formations. These veins are sometimes arranged in groups following the shear zones, but are seldom of sufficient width, nor closely enough bunched, to be worth working. For the most part the gangue material is quartz, but occasionally some carbonate accompanies the siliceous matter. Needles of black tourmaline are frequent in veins of this type and occasionally occupy the entire width of the vein. The sulphides, pyrite, pyrrhotite, and chalcopyrite, are to be found, and galena is a very rare constituent. Veins of this kind occur, as a rule, either in the acid volcanic schists or at the contact of an acid and a basic flow, but, in places, they run into the basic rocks. For the most part the acid volcanics are more schistose than the basic rocks and seem to have provided a better opportunity for the formation of the veins. The presence in the acid rocks of more carbonate than in the basic rocks may have been the determining factor in the deposition of the metallic content in the veins, and may explain the greater amount of sulphides contained in the veins cutting the acid rocks. The presence of tourmaline and pyrrhotite, both high temperature minerals, points, apparently, to a pegmatitic origin for these veins. These "shear-veins" are seldom more than a few inches wide nor continuous in length for more than a few feet. The vein-forming solutions have impregnated the wall-rocks on either side for a few inches so that values may be obtained a short distance away from the vein.

[1] Loc. cit.

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The second type of vein cuts across the schistosity of the rocks at various angles. This type is found cutting two formations in different parts of the field. East of the Algoma Central railway, veins of this type cut across the acid volcanics of the quartz porphyry and feldspar porphyry types, whereas west of the right-of-way on the claims owned by M. Gutcher, of Goudreau, similar veins cut the granite boss already described.

These two phases of the "cross-vein" type are quite dissimilar and will be discussed separately. The veins cutting the acid volcanics of the Keewatin vary in width from a few inches to 2 feet or more and, in places, as on the McCarthy-Webb property in township 27, range XXVII, they may be traced for 20 or 30 feet. They carry, beside the usual quartz content, pyrite, native gold, and numerous black needles of tourmaline. They are, as noted by Collins, younger than the "shear-veins," and, in places, cut across them. The mineral solutions have not, apparently, impregnated the wall-rock to the same extent as in the case of the "shear-veins." Like the "shear-veins," these veins are, for the most part, neither continuous nor wide enough to exploit. In a few cases several of them may be bunched close together, but the gold values appear to be too uncertain to ensure payable production. Cross-veins of this type are found intersecting the iron formation of the district. Occasionally the iron formation rocks carry gold values which appear, on casual inspection, to come from the iron formation itself, but on closer examination these are found to be due in every case to "cross-veins" or stringers of quartz which vary in width from paper thickness to 3 or 4 inches. These "cross-veins" have not been found of sufficient size to encourage development.

The "cross-veins" cutting the granite boss probably represent the most acid phase of the pegmatite dykes. This type was observed only on the Gutcher claim where the veins are very irregular in width and extent and carry considerable pyrite and covellite as well as a little free gold, chalcopyrite, and muscovite. This type of vein is described in more detail on page 25.

The last type of vein is found only in the Murphy group. This vein is of the fissure type and angles across the strike of both the acid and basic volcanics of the Keewatin series. As it is cut and slightly faulted by a younger diabase dyke its deposition must have preceded the intrusion of these dykes.

The prevalence of tourmaline in all these types suggests that the gold-bearing solutions were an integral part of the last juices of the granite magma. The fact that the Keewatin rocks in this district are surrounded by granite, and the appearance of a small granite boss near the Murphy claims, indicate that granite underlies a comparatively shallow covering of older Keewatin rocks. If this be the case, the injection of pegmatitic mineralized solutions into the cracks and fissures of the overlying Keewatin rocks would be a natural consequence of the last stages of cooling of the granite magma. The presence of tourmaline in most of these veins supports this theory. The metallics pyrrhotite and chalcopyrite might also be expected under such conditions. That native gold has been found on the Gutcher claim in quartzose veins of the pegmatite type, cutting the boss of granite, shows that gold-bearing solutions were not foreign to the granite body itself.

Description of Properties

McCormick. This property, SSM 2183, is situated in township 26, range XXVII, east of Pine lake. A fairly good wagon-road runs from Goudreau station to the east end of Pine lake, whence a very good trail leads to this and adjoining claims. An alternative route is by wagon-road to Teare lake and thence by lake and portage to the east end of Pine lake where the aforementioned trail may be picked up. A shallow pit about 9 feet deep has been sunk on the band of iron formation in basic Keewatin volcanics, with a strike of 70 degrees and a dip of 70 degrees to the north. This band, which is from 2½ to 4 feet in width and about 70 feet long, carries considerable amounts of pyrrhotite and quartz as well as minor amounts of chalco-

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pyrite, pyrite, sphalerite, and carbonate. Gold values at the shaft are said to vary from $46.60 on the surface to $19.20 at a depth of 4 feet. No values of consequence have been obtained from other parts of the band.

Fuller-Black SSM 2184. This property adjoins the McCormick on the west. At the contact between acid and basic Keewatin flows, at a point near the south boundary of this claim, a small quartz stringer carries pyrrhotite, chalcopyrite, and pyrite, as well as some free gold. The acid rock, which is a quartz porphyry, lies to the north, and the basic rock to the south. The rocks and the vein strike at 107 degrees and vary in dip from 70 degrees to the north to vertical. The basic Keewatin carries considerable pyrite and has a rusted appearance 15 or 20 feet south from the contact. Values of $25 a ton in gold are reported to have been obtained from this stringer.

Cline, SSM 2185. This claim is north of 2183 and east of 2184. It is owned by J. P. Cline, of Goudreau. The gold values here have been found in a band of sulphide-bearing basic Keewatin volcanic at the contact with the acid quartz porphyry, both rocks striking east and west and having a vertical dip. This band is said to carry values in gold up to $6.

Cline, SSM 2186. This claim adjoins 2185 on the east. Four small pits have been sunk, three close to the western boundary and the fourth near the centre of the claim. The first is a shallow depression where a few shots have been put in after stripping. Here a narrow band of acid Keewatin volcanic from 8 inches to 3 feet in width, shot through with small "shear-veins" and "cross-veins" of quartz carrying pyrite, pyrrhotite, tourmaline, and a little native gold, is intercalated in the basic Keewatin rocks. This band has a strike of 105 degrees and a vertical dip. Gold values at this point are said to range from $5 to $150 a ton.

About 200 feet east of this is another shallow pit, sunk on a quartz vein 6 inches to 1 foot wide, with a schisted zone 4 feet wide, carrying smaller "cross-stringers" next to the foot-wall. The vein strikes east and west and dips at an angle of 75 to 80 degrees to the north. The wall-rock is basic Keewatin. The vein carries much the same metallic constituents as at the first pit and shows gold values which are said to range from $22 to $24 a ton.

At the last pit a 10-foot hole has been sunk on a quartz vein 2 inches to 1 foot wide, with a schisted zone 2 to 3 feet wide immediately south of the vein. The country rock on either side is a coarse basic Keewatin volcanic. The vein, which carries pyrite, pyrrhotite, magnetite, and a little free gold, strikes east and west and dips 85 degrees to the north. Free gold has been found for about 35 feet along this vein, which has a total length of about 50 feet, but average samples have not been taken. Grab samples are said to have given high values. Pit No. 3 is about 100 feet north of the second pit and is sunk on a composite quartz vein, 20 to 30 inches wide, with a strike of 118 degrees and a dip of 70 degrees to the north. This vein, which parallels the schistosity of the basic Keewatin through which it runs, carries pyrite, magnetite, and tourmaline. A more solid band of quartz near the foot-wall carries the gold values, which are not high. A sample taken by Collins in 1919 from a vein 10 inches wide which lies about half-way across the claim and 300 feet north of the trail, was assayed by the Department of Mines and found to contain $1.20 of gold a ton.

Cline, SSM 2189. This claim is one claim east and one claim south of SSM 2186. Close to its northeast corner a pit 25 feet deep has been sunk on some small quartz stringers, samples from which are said to have yielded very high values in gold. These stringers cut the basic Keewatin rocks for the most part, but also a narrow acid flow to a minor degree. Both flows, which strike east and west and have a vertical dip, are cut by a younger diabase dyke with a strike of 165 degrees.

Webb, SSM 2470. This property, which is owned by Joseph Webb of Sault Ste. Marie, is situated near the east end of Godin lake in township 25, range XXVII, near

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the line between townships 25 and 26. It may be conveniently reached by water-route from Lochalsh, a station on the Canadian Pacific railway east of Franz; or less easily by a continuation of the same route by which the Cline claims are reached from Goudreau. The country has been recently burnt over in that vicinity so that the rocks are well exposed in most places. The gold values have been found in a band of discontinuous "shear-veins" occurring in the schistosity planes of the basic Keewatin rocks. These rocks have a strike of 100 degrees and a vertical dip. This band is said to extend for 1,700 feet, but only 200 to 300 feet of it was seen by the writer. The stringers vary in width from a few inches to 6 or 10 feet and there are some "cross-stringers" cutting them in places. Gold values have been obtained from this band, which carries some pyrite. At a small pit east of the main showing, a composite vein of quartz and basic Keewatin rock, with a width of about 6 feet, carries considerable carbonate. The country rock here also is basic Keewatin.

Webb-McCarthy, SSM 2049 and 2050. These claims are owned by Joseph Webb and D. J. McCarthy, of Sault Ste. Marie, and are situated near the south boundary of township 27, range XXVI, on the north shore of Iron or Webb lake. The gold showings are in an acid Keewatin flow, which occupies the north half of the claims, and which is in contact with a basic flow to the south. This acid volcanic corresponds to a highly silicified quartz porphyry schist and is seamed with numerous "shear-veins" and "cross-veins" which carry the gold. The schist strikes about east and west and has a dip of 70 to 80 degrees to the north. The contact between the two flows, however, runs to the south slightly, and the veins on the adjoining claim to the west (2051) are also to be found in the same acid flow. Neither the "shear-veins" nor the "cross-veins" which intersect this flow are continuous for any considerable distance, 200 feet being the maximum, the width varying from 2 inches to 16 inches. Both types of vein carry considerable black tourmaline as well as some pyrite and free gold In one or two of the "shear-veins" tourmaline occupies the entire width of the vein. The rock itself is in many places impregnated, a short distance from the vein, with both pyrite and tourmaline. The "shear-veins" are about twice as numerous as the "cross-veins". At the contact of the two flows a small vein shows exceptionally high values in gold. Most of the showings of free gold are on claim 2050. Just east of the west boundary of 2049 an olivine diabase dyke outcrops, and no showings were observed east of this dyke.

Webb-McCarthy, SSM 2051. No work of consequence has been done on these claims since Collins described them. They occur in the same acid flow as those on 2049 and 2050. The "cross-veins" are rather larger and contain considerable black tourmaline.

This set of three claims is readily accessible by road and trail or by road and canoe-route from Goudreau station.

Banville-Pagé. Claim 532 owned by J. Banville and O. Pagé is situated on the north shore of Rowan lake in the middle of township 28, range XXVI (Figure 2) and west of the Algoma Central railway. All those previously described lie several miles east of the railway (Figure 1). A fair wagon road runs from Goudreau station to the Murphy claims passing along the south shore of Rowan lake, from where a canoe or boat must be taken to the claim. An alternative route is by canoe through a string of lakes and portages. Gold has been found on this claim in a contorted band of iron formation cut by numerous "cross-stringers" of quartz. The iron formation consists chiefly of carbonate and quartz. The country rock is a basic Keewatin schist, with a strike of 105 degrees and a vertical dip. The "cross-stringers" contain a little chalcopyrite as well as occasional flakes of gold, a few "shear-veins" were observed in the country rock. The iron formation is only 6 to 10 feet in width, and is contorted locally in the form of an overturned fold, with the axis of the fold pointing northwest. A 6-foot pit has been sunk on this band.

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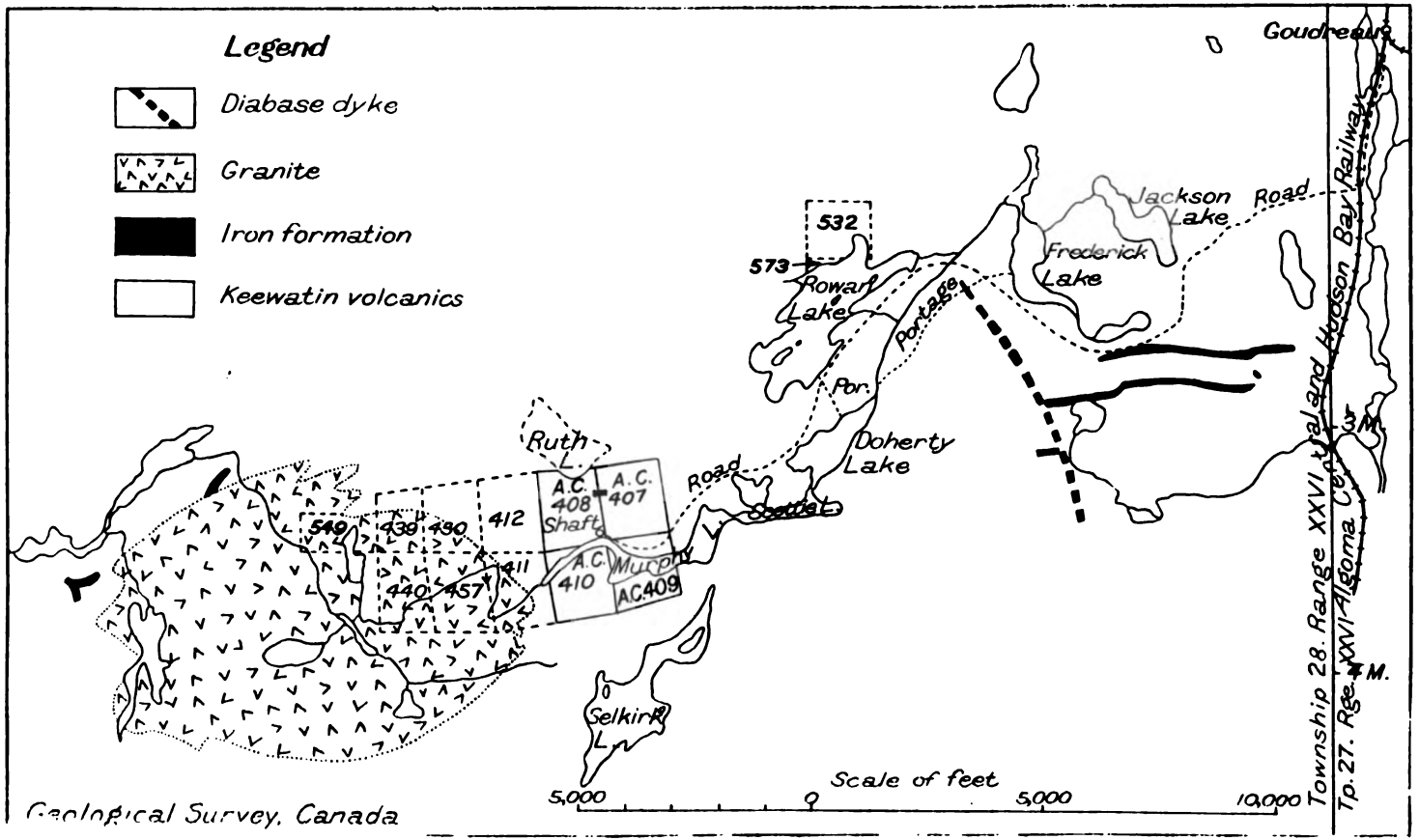

Figure 2. Diagram showing location of Murphy claims (A.C. 407-410), Banville claims (573 and 532), and Gutcher claim (549), Goudreau area, Algoma district, Ontario. Note: Claims shown by broken line are unsurveyed.

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Gutcher, SSM 549. This property, which is in township 28, range XXVI, lies west of, and is connected by trail with, the Murphy claim. The granite boss already mentioned outcrops on this claim and the gold-bearing veins are evidently quartzose phases of pegmatitic dykes representing the last stages of cooling and differentiation of the granite magma. The granite shows gneissoid structure in places and in others merges into a coarse quartz porphyry. The veins cutting the granite have been classed with the "cross-veins" for the sake of convenience, although they do not show the same characteristics as the "cross-veins" cutting the Keewatin volcanics. Gold has been found in a quartz vein 1 to 3 feet wide carrying considerable pyrite, covellite, and muscovite, as well as some little chalcopyrite, malachite, and ankerite. This vein has a strike of approximately 125 degrees and dips at an angle of 70 degrees to the north. It has been traced for 200 feet and in one or two places has side stringers. A larger quartz vein a short distance away in the same kind of rock has a maximum width of 12 feet, but, so far as the writer was able to observe, carries no values.

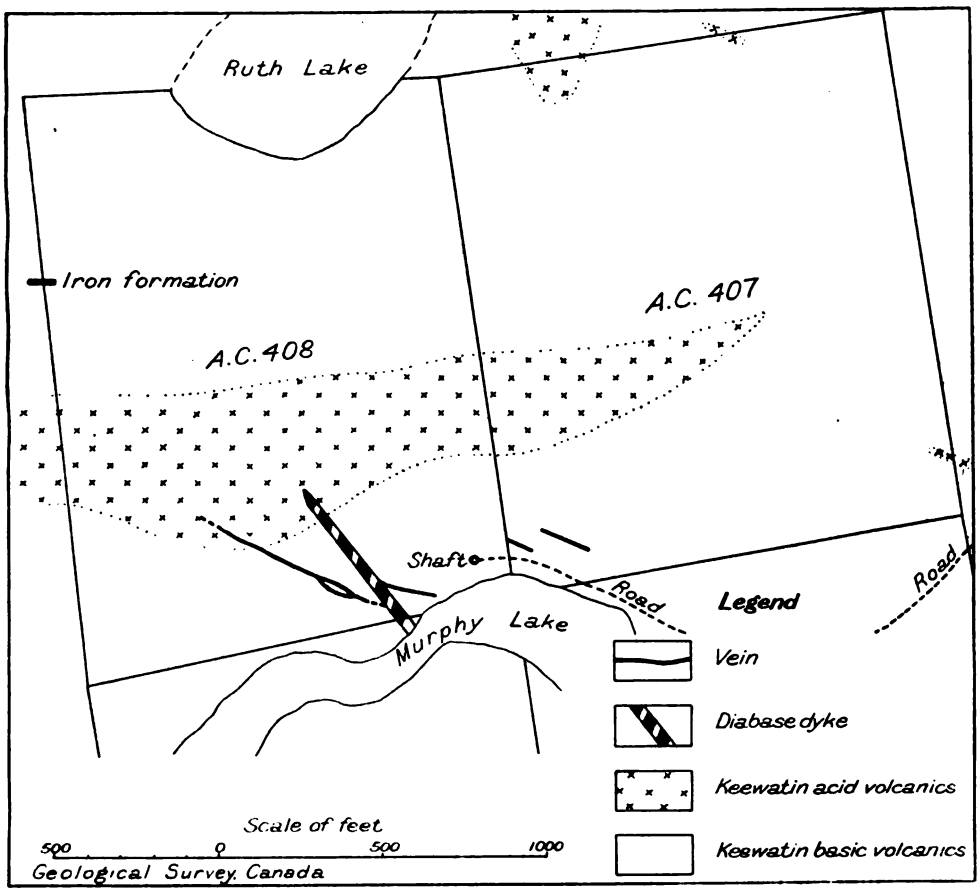

Figure 3. Diagram showing geology of Murphy claims, A.C. 407 and A.C. 408, Goudreau area, Algoma district, Ontario.

Murphy Claims. In township 28, range XXVI, on the north shore of Murphy lake, a group of four claims, 407 to 410, were staked by Thomas Murphy and James Perry, of Goudreau. The first discovery was made in a quartz vein in claim No. 408 where quite coarse gold was found at several places in a distance of 20 feet. In the month of September these claims were surveyed. A fair wagon road connects these claims with Goudreau station, 5 or 6 miles distant. An alternative route is by a string of lakes and portages. Most of the work has been done on 408, in the south-east corner, where the best gold showings have been found. Several acres of ground

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have been cleared and the vein has been stripped for its entire length and sunk on for 20 feet. Although the vein is confined chiefly to 408, small stringers are found in the adjoining claim 407. The main vein has a strike varying from east and west to 295 degrees and a dip from 60 degrees to the south to vertical. It has been traced for about 800 feet, with a width of from 1 to 10 feet. Its country rock is for the most part basic Keewatin, but it intersects an acid flow toward its western end, both with a strike of about 100 degrees and a vertical dip. The gangue material is chiefly quartz with numerous small needles of tourmaline which give it a black colour. The metallics are for the most part native gold, pyrrhotite, and chalcopyrite, but appreciable amounts of bornite, pyrite, and sphalerite are also found. Running parallel with the vein for a considerable distance, and occupying part of the same fissure, is a band of carbonate iron formation which weathers on the surface to limonite. The country rock for about a foot on either side of the vein has been largely impregnated with quartz and the metallic constituents of the vein. At one point the vein has been offset 76 feet on a bearing of 230 degrees by a younger diabase dyke about 50 feet wide, which strikes at 140 degrees. Native gold has been found at numerous places along the vein and a good showing was noted by the writer at the bottom of the 20-foot shaft.

Regarding another vein, Mr. Burrows reports as follows in his preliminary report issued last summer. Work has also been done on claim 407 to the east. At the west line, 200 feet north of Murphy lake, a narrow quartz vein about a foot in width has been traced 65 feet; it strikes south 80 degrees east. The wall-rock for a few inches is quite rusty and carries sulphides. Visible gold was observed at two points along the vein. About 200 feet easterly from the west line work has been done on a wide ankerite-schist band up to 20 feet in width, which carries quartz veins roughly parallel with the ankerite band. It has been traced for 170 feet in a direction south 70 degrees east. No visible gold was observed in this vein, but at one point an assay of $6 in gold was obtained over a width of 2 feet 9 inches of quartz and $4 in gold over a width of 5½ feet of the schist and carbonate, carrying quartz, lying to the north. Owing to the highly altered character of the schist by oxidation, the latter assay is only indicative of the presence of gold which may be concentrated. The quartz vein carries pyrite, copper pyrites, pyrrhotite, and a little zinc blende. It is possible that this easterly vein is the faulted part of the vein exposed on claim 408.

These four claims were worked on option during the summer of 1921 by A. R. Porter, Toronto, but later the property was taken over by a group of Toronto men. Claim 408 appears to be much the most promising in the district and the only one where the vein holds its values for more than a few feet. Being of the fissure type, the values probably hold at depth. Considerable native gold was located at the 20-foot level.

The writer has purposely confined his descriptions to those claims showing gold, and has made no mention of the numerous other properties that have been exploited in the hope of getting values.

On the way back to Toronto the writer stopped at Bruce Mines, at the request of Daniel MacDonald of that place, to examine a gold prospect in the greywacke formation. The gold was discovered in the bed of Thessalon river in the southwest quarter of section 9, Lefroy township, Algoma district, in a loose boulder of greywacke of the Gowganda formation. It occurs in small quartz veins following the joint planes in the rock. The boulder is said to be angular in outline and consequently unlikely to have travelled far, but at the time of the writer's visit was under water. The quartz stringers were very small, seldom exceeding one-half inch in width. The big fault which runs easterly through this section of the country is located in the bed of the river at this point and the movement which produced it may have shattered the neighbouring greywacke formation for the reception of these tiny veins. Diabase sills are in fairly close proximity, and these are known to have been the cause of gold-bearing veins, such as occur at the Havilah mine, about 10 miles north of the locality where this boulder occurs.

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DEROCHE, HODGINS, GAUDETTE, AND SHIELDS TOWNSHIPS, ALGOMA DISTRICT, ONTARIO

By Sir Stopford Brunton

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Map 1936. Shields, Gaudette, Deroche, and Hodgins townships, Algoma district, Ont.. 27

INTRODUCTION

For many years iron ore has been reported from various places on the line of the Algoma Central railway, and a considerable amount of prospecting has been done from time to time. Some of these ore outcrops have attracted attention lately, and the writer was detailed by the Geological Survey to investigate and map geologically an area comprising the townships of Deroche, Hodgins, Gaudette, and Shields, to determine the nature and extent of any occurrences of iron ore which might be found.

Two months were spent in the area, during which the writer was assisted by Mr. Walter J. Kingsmill, and during one month the party was augmented by F. Wright and Mr. G. Bain. Mr. G. S. Cowie, secretary of the Mines Department of the Algoma Steel Corporation, also assisted materially and is deserving of many thanks.

GENERAL CHARACTER OF THE AREA

The area is situated on the Algoma Central railway about 20 miles north of Sault Ste. Marie, Ont. Travel away from the railway is difficult as there are no streams on which a canoe can be used, and only one or two roads. A good road runs from the Sault to Bellevue at the southwestern limit of the area, and another is being built from Wabos to Glendale with the ultimate intention of connecting the district with the Sault either via Bellevue or by the old Garden River road, which has been abandoned for fifteen or twenty years and is at present impassable.

The country taken as a whole is one of comparatively low relief, the hilltops reaching about 1,500 feet above sea-level. The difference of elevation between the hills and valleys is 400 to 500 feet, and the hillsides are steep, rendering any passage through the area difficult. Nobody lives in the district except along the railway line and in a few of the valleys closely adjoining it. The area has been burned in places and lumbered over, so that a large part is covered with berry bushes and second growth. There are a few lakes, all too small and disconnected for canoe work, and the streams are mere rivulets over falls, and are dry, or almost dry, in summer.

GENERAL GEOLOGY

The rocks can be classified under the following divisions:

Pleistocene	Lake and glacial deposits
Keweenawan	Diabase dykes
Huronian	Lorrain quartzite
Pre-Huronian	Granite complex Schist complex consisting of volcanics and some associated sedimentary materials

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PRE-HURONIAN SCHIST COMPLEX

The Pre-Huronian complex is a very involved mixture of schists, including hornblende schist, diorite, diabase, and even more basic rocks invaded and metamorphosed by batholithic masses of granite and gneiss. The schists underlie the southwestern part of the area, and consist of volcanic flows and tuffs, with some interbedded conglomerate. They have been dislocated and metamorphosed to such an extent that a detailed separation was not possible in the time available. The volcanic element of the series, in some places shows distinct bedding and very fine texture as if it had been laid down under water, in others it shows vesicular structure, and yet in others volcanic bombs are clearly discernible. The strike and dip vary greatly; the strike varies from north 70 degrees west to north 55 degrees east and the dip from about 20 degrees to almost vertical; there appears to be no system in the strike and dip, and the rocks seem to lie anyhow.

Some of the outcrops may be described in greater detail. On the road to the San Antonio Mine Company's house at Maple lake is an agglomerate consisting of aggregates of quartz and feldspar crystals, both orthoclase and plagioclase, in a groundmass composed of fine-grained fragments.

Near Midge lake a fine-grained mass of uniform texture is composed for the most part of chlorite. In the hand specimen thin bands can be distinguished and these also appear in the thin section showing a difference in composition, for whereas one band is for the most part chlorite another is made up chiefly of quartz grains.

A short distance from the outlet of Midge lake another type can be seen, namely a porphyrite having large phenocrysts of hornblende enclosed in a cryptocrystalline groundmass, the whole highly impregnated with iron so that the rock has a bright red appearance.

The occasional interbedded conglomerates are formed of a matrix of fine-grained material containing pebbles, mostly of granite, ranging up to 6 inches or 8 inches in diameter. These beds are not regular nor do they run continuously for any great distance, nor have they the appearance of basal conglomerates. Outcrops were found to the north of the Algoma Steel Corporation's quarry in Vankoughnet township, on the eastern edge of Loon lake, at the junction of Dam creek with Stony creek, and in the eastern branch of Shepherd creek near the Campbell Murdoch claims; in the two last-mentioned places the conglomerate showed evidences of crushing and faulting. Both the volcanics and sediments show signs of contact metamorphism, and are cut by dykes of fine-grained granite.

GRANITE

Although there is only one colour used upon the map to indicate granite, there are probably two granites of different ages in the district. The granite underlying the whole southern part of the area is different from the granite north of Goulais river, in that it does not contain inclusions of hornblende, schist, etc.; and is of a comparatively uniform composition over an area comprising the southern part of Deroche and the northern half at any rate of Jarvis. This part of the area has a distinctive physiographic relief, for whereas the ridges formed of the Pre-Huronian volcanics and sediments, and even those formed of the Huronian quartzites, have a well-marked northwest-southeast trend, the granite has no such features, but is composed of small hummocks with intervening depressions, in which the water flows in all directions indiscriminately. Dykes of granite have been found cutting the Huronian sediments.

A specimen of granite from the north bank of Goulais river is white and fine-grained; in places this rock has been so much deformed as to lose all the normal characteristics of granite. The thin section shows mostly quartz and feldspar, both orthoclase and plagioclase, and an almost entire absence of ferromagnesian minerals with the exception of a little mica and some accessory epidote. The grains are all crushed and broken, the feldspars are deformed, and all the grains show strain shadows, as if the rock had been subjected to great stresses. On the other hand two specimens from just south of the Goulais are composed of pink feldspar and much ferromagnesian mineral. The thin section shows quartz orthoclase, microcline, biotite, leucoxene, horn-

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blende, and accessory apatite. The rock is entirely unaltered and shows no signs of fracturing or strain shadows. It is doubtful if specimens with such different characters both of composition and structure represent the same rock. The southern granite is in part at least younger than the Pre-Huronian volcanics and sediments and may even be intrusive into the Huronian; in other words it is probably allied to the Killarney granite.[1]

HURONIAN

Near Bellevue is a small area 3½ miles long and from ½ to 1 mile wide, underlain by Huronian rocks, which Collins considers to be the Lorrain quartzite of the Cobalt series. This quartzite, varying from fine to coarse-grained beds, contains pebbles up to 2 or 3 inches in diameter. These pebbles are for the most part granite, but there are many of bright red jasper. The texture of the rock varies from a hard siliceous quartzite to soft beds of sericitic sandstone which show very fine ripple-marks and evidences of shallow water or subaerial deposition; from the peculiar appearance of some of the beds Mr. Kindle concludes that they originally contained oolitic grains which have since been leached away. The beds strike fairly uniformly north 70 degrees to 75 degrees west, but the dip varies between 35 degrees and 75 degrees north. They lie unconformably upon the Pre-Huronian volcanics and sediments, and are cut off, to the south and southeast by the granite, to the north and northwest by the Pre-Huronian. Near mile 20 on the Algoma Central railway there is a quarry belonging to Wright and Company, from which the Algoma Steel Corporation get a supply for their furnaces at the Sault. Approximately 10,000 tons were quarried last year and the same quantity is expected for this year. An average sample analysis from several carloads gave: silica, 96·55 per cent; iron, 2·57 per cent; alumina, 0·61 per cent; lime, 0·41 per cent; but several analyses ran 98 per cent silica or even higher. A specimen from this quarry shows in thin section a rock almost entirely composed of silica grains 1 to 2 millimetres in diameter, very angular and showing strain shadows. In the quartzite beds are several cracks filled with a fine-grained red detritus carrying angular fragments of breccia. Veins of specular hematite, also, cut the quartzite.

Records of diamond drilling on mining prospects occupying lots 6 and 7, concession II, Deroche township, are as follows:

"*Diamond Drill Exploration, Hawkshaw-Derrer Property, near Northland Station, A.C.R. Township of Deroche*

Drilling of Claims Nos. SSM 1070, SSM 103, Lots 6 and 7

No. 1 Jan. 11, 1910			No. 2 Feb. 8, 1910			No. 3 Mar. 11, 1910		
from	to		from	to		from	to	
0 ft.	19 ft.	Casing	0 ft.	35 ft.	Casing	0 ft.	42½ ft.	Casing
19	208	Quartzite	35	262½	Quartzite	42½	50	Greywacke
						50	63	Quartzite and greywacke
						63	69	Slate and quartzite
						69	73	Quartzite
						73	123	Slate
						123	224	Slate and quartzite Banded
						224	260	Quartzite and slate
						260	267½	Quartzite
						267½	274	Quartzite
						274	330	Slate and quartzite
						330	402	Banded quartzite, slate, and greywacke
							402	Mixed
						402		5 inches hematite
						402	410	? ? ?
						410	470	Quartzite and slate

NOTE. No ore shown on this property by diamond drilling."

[1] Geol. Surv., Can., Sum. Rept., 1920, pt. D.
Geol. Surv., Can., Mus. Bulls. Nos. 8 and 22.

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The names are copied from the engineer's blueprint, but no examination could be made of the cores and what has been classed as greywacke is probably Pre-Huronian volcanic rock.

DIABASE DYKES

The whole area is intersected by diabase dykes in all directions. This conforms very closely to the description given by Collins of the diabase dykes in Goudreau and Magpie-Hawk areas.[1] These dykes are of two varieties: (1) a quartz diabase such as the large dyke running from the quarry near Bellevue to Loon lake; and (2) an entirely quartz-free diabase which is found cutting the granite in the southern part of the area. As in the Goudreau area, so in the Deroche area, some of the quartz diabases are very hard to distinguish from the Pre-Huronian greenstones, and are in many places sheared and faulted. The quartz-free diabase is much fresher in appearance and shows none of the shearing referred to in the quartz diabases.

PLEISTOCENE

Lying unconformably upon the Precambian are deposits of Pleistocene clays, sands, and gravels, which in some cases have been laid down in rivers and lake bottoms, but in others are due to morainal action. Several terraces can clearly be distinguished: at Ed. Pognant's house near mile 20 there is a considerable stretch of one of these terraces (elevation 1,115 feet by aneroid barometer) to the north of the railway track, and just south of the track is another terrace (1,175 feet, aneroid). A succession of terraces occur up Goulais river from Searchmont to the Falls at elevations of 835 and 855 feet, each terrace being distinctly defined. Near Wabos station are two terraces, 962 and 973 feet respectively.

Along the banks of Goulais river near Bellevue the deposits are of clay, sometimes attaining a thickness of 50 feet, and fine sand. Crossbedding and minor unconformities can be seen in the cuttings along the railway. Towards the north, however, a change takes place and the deposits along Achigan creek are composed of coarser sand carrying pebbles and boulders intermixed, showing the characteristics of morainal origin.

FAULTING AND FOLDING

The Goulais valley is a very striking physiographic feature, running as it does for nearly 12 miles in a straight line. North of it, though not so apparent, owing to its greater inaccessibility, is a parallel valley along which runs the east branch of Shepherd creek. At the junction of Dam creek (which is simply the continuation of the Goulais) and Stony creek, the rocks show evidence of faulting, and the granites near Searchmont show similar evidence of severe deformation. The big diabase dyke which runs parallel to the Goulais just south of the railway is possibly associated with this movement. Loon lake, also, occupies a fault zone, granite occurring on the east side and steeply tilted volcanics on the west. The trend of this zone is northwest-southeast.

There are, probably, at least two systems of faulting: an east-west system which controls the valley of Goulais river, and a northwest-southeast system which seems to be more recent than the east-west, as the diabase dyke parallel to the Goulais is cut off at Loon lake and deformed and all the east-west veins on Mr. Mason's prospect are cut by the northwest-southeast veins which are continuous.

[1] Geol. Surv., Can., Sum. Rept., 1918, pt. E.

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ECONOMIC GEOLOGY

IRON ORES

The occurrences of iron ore in Deroche and adjoining townships differ considerably from the deposits of ore known as iron formation. Those in Deroche township consist for the most part of hematite and specularite associated with quartz veins which cut the Pre-Huronian volcanics. Those in Shields have much more the appearance of chemical precipitates.

Two properties have been developed to a point at which they can be designated as mines, but neither is now in operation. The Breitung mine was opened up twenty-two years ago, and ore was shipped to Northland on a switch-line built from the Algoma Central railway. The Breitung Iron Mining Company, Marquette, Mich., now owns the property. The ore-body lies in the side of a steep hill about 300 feet high, half-way down the west side of Loon lake. Two adits were driven into the hill, one about 80 feet above the lake, the other about 75 feet still higher. An open pit, a shaft, and a few shallow workings may be seen about 200 feet above the lake. The wreckage of a small steam winding plant lies at the foot of the hill.

The rock at the mine is a slate-coloured, finely bedded greywacke, sharply folded and evidently of pre-Huronian age. The ore-body occupies a zone which has been fractured and shattered into a breccia and afterwards recemented with quartz and specular hematite. In most places there does not seem to be more than 10 or 15 per cent of metallic iron present, but locally where brecciation was most intense the iron oxide has either penetrated in larger amount, or has chemically replaced part of the greywacke, yielding a low-grade ore carrying possibly 30 or 40 per cent of iron. Apparently it was these rich spots that induced mining operations. The better-looking material is limited at the shaft to a width of about 30 feet, but leaner mineralization occurs almost to the foot of the hill. The general trend of the mineralized belt appears to be nearly parallel to the length of the lake.

The Williams mine is situated at the corner of the four townships Deroche, Hodgins, Jarvis, and Anderson, about 1½ miles east of the southern end of Loon lake. The property was first located twenty years ago and in 1903 a shaft was sunk. This shaft is 212 feet deep to the sump, from the bottom of which diamond drill holes were put down 300 feet farther, some vertical and some at 45 degrees. The levels were run at 100 and 200 feet. This property was worked for about two years and about 500 tons of ore were shipped on sleighs to Northland. The shaft cannot now be examined owing to water, but the ore-body is supposed to be similar in general character to the Breitung deposit.

A short distance north of the Williams mine on the eastern side of Loon lake, near Midge lake, a prospect was opened up in the spring of 1921, by Mr. E. P. Mason, who has done some stripping over an area 500 feet by 300 feet and has exposed the rock surface very well. The rock is a mixture of granite and Keewatin diabase, and the ore occurs in conjunction with quartz veins in a manner similar to the occurrences at the Williams and Breitung mines. There are two distinct sets of veins, a northwest-southeast set, and an east-west set; of these the northwest-southeast set is the more recent as all the veins are continuous at the junctions, whereas the veins in the east-west set are cut off or show signs of displacement. A drill hole has recently been put down at an angle of 40 degrees to a depth of 510 feet. It discloses almost the same rock conditions as at the surface: an alternation of Keewatin greenstone and bands of intrusive granite, with here and there quartz veins carrying an insignificant amount of specular hematite.

The occurrences of ore in all these places are very much alike and appear to be impregnations (with some replacement) in the sheared rocks of fault zone. It is very doubtful if any body of ore large enough for commercial development will ever be found in this vicinity.

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The Campbell claims in the northern part of lots 6 and 7, concession VI, of Deroche, and the adjoining portion of the township of Shields were also visited. The ore here contains magnetite, but the dip needle showed very little attraction.

These claims were visited in 1910 by Mr. Sjostedt who says: "The iron occurs in a contact between the Laurentian and Huronian formations. The rocks on the west side are granite, gneiss, syenite, etc., while those on the east side are Huronian schists. The walls where visible are well defined." He also gives the iron content of the ores as varying from 38·83 per cent to 58·93 per cent.

In 1914, John A. Dresser visited the claims and wrote:[1] "The rocks seen upon the property, with the exception of certain dykes, likely all belong to the Keewatin series, hornblende schist, hornblende gneiss, and diorite may be distinguished, but exposures of fine-grained greenstones predominate. Outcrops of a coarse-grained basic syenite dyke (locally called granite) were seen along the western side of the beaver meadow near the camp. At various places on the property are to be seen outcrops of nagnetite-bearing bands. These appear too siliceous to form a merchantable ore and may be better described as banded iron formation. The formation is sufficiently different in character from what is described as 'banded iron-formation' in other localities to require special description. Here neither the bands of ore nor the siliceous bands have clear-cut boundaries. Both lie in narrow, parallel streaks, the magnetite apparently blending gradually into siliceous material. The banding is made apparent chiefly by the bands of nearly white silica, and occasionally by bands of reddish garnet. On surface exposures the banding is much more conspicuous than on fresh surfaces, as the magnetite has weathered faster than the siliceous and garnetiferous bands and so is low in relief compared with them. On the series of exposures stretching northwestward from the beaver meadow the strike of the iron formation seems pretty uniform and is about north 30 degrees west; the dip is about vertical. On the other series to the northeast along the trail from Wabos the strike varies from northeast and southeast to east and west; the dip is vertical. At some of these later exposures intrusive granite dykes are exposed, which evidently have disturbed in some degree at least the previous position of the iron formation."

A consideration of the whole area only confirms the doubt that economic deposits of iron ore will be found in any of these four townships.

LEAD ORE: VICTORIA AND CASCADE MINES

These mines are outside the area under consideration, in lots 4 and 5, concession III, Jarvis township, which adjoins Deroche on the south. The mines are supposedly lead mines, but are at present shut down for lack of ore. They were opened about fifteen years ago and, about 1910, a new set of machinery was installed at the Victoria mine. Both mines are situated on Driving creek, the Victoria one-half to three-quarters of a mile below the Cascade. At the latter there are, apparently, two small veins of calcite carrying a little galena; at the former there certainly does not seem, from superficial evidence, to be sufficient ore to warrant the construction of a mill.

The object of the visit to these mines was to ascertain if Huronian rocks were in this vicinity. From Loon lake to the mines the only rocks seen were granite and diabase, the granite being pink and in every way resembling that near Northland. A large mass of coarse-grained diabase, as well as various fine-grained dykes, was found near the mines themselves.

A trip northwards from Garden River as far as the mines showed that Huronian rocks are to be found to within a short distance south of them. R. G. McConnell, whose courtesy the writer greatly appreciated, is investigating this area for the Ontario Bureau of Mines.

COPPER ORE: SUPERIOR MINE

This mine lies on the northern boundary of the township of Gaudette. After a shaft had been sunk about 400 feet operations were suspended and the shaft was allowed to fill with water. During the summer of 1921 the shaft was pumped out

[1] Information supplied through the courtesy of the Algoma Steel Corporation.

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and the mine was prepared for examination with a view to purchase. There was originally a spur line from mile 39½ on the Algoma Central railway, but this has fallen into disuse and the rails have been carried away. The old bed, however, can be used as a wagon road. The railway track traverses for the most part rocks of the Pre-Huronian complex comprising dark gabbro-like rocks with inclusions of hornblende schist, mixed with granite, and the whole cut by pegmatite dykes. In the immediate vicinity of the mine there is a mass of greenstone and about 500 yards along the track is a diabase dyke about 200 feet wide. The ore, which is a mixture of pyrite and chalcopyrite, occurs associated with quartz stringers in a brecciated zone in the greenstones. No evidences of any large mass of ore were found in the vicinity.

BRICK CLAYS

Outcrops of stratified clay are abundant along the banks of Goulais river south and west of Searchmont. The most extensive and important outcrops are about one mile west of Glendale where the clay outcrops for over 1,000 feet along the river. The average exposed thickness is about 20 feet, but in one place it is 50 feet thick. In no case was the base of these clays seen. They are overlain by unstratified, or very poorly stratified, gravel and sand, probably river-worked glacial materials.

These clays are light grey, fine-grained, and highly calcareous. They are very finely laminated, due to alternation of layers of clay and sandy clay, and originated, probably, in an arm of lake Algonquin, a predecessor of lake Superior, which must have extended up the Goulais valley beyond Searchmont.

Two small samples from these deposits were submitted to the ceramic laboratory of the Mines Branch, with the following results.

"When gauged with water they develop very poor working properties, being very weak and flabby. When passed through a tile die, the test pieces deform from their own weight. Both clays will stand rapid drying.

The following are the burning tests of the wet-moulded bricklets:

Sample	Cone	Fire shrinkage	Absorption	Colour
		%	%	
6 F	06 3	5 softens	20	Dirty buff
7 F	06 3	5½ softens	19	Dirty buff

6 F Algoma Central Railway mileage 32½, near Searchmont.
7 F Goulais river, one mile west of Glendale.

They are both low-grade clays useful only for making common stiff mud-bricks."

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WANAPITEI LAKE MAP-AREA

By T. T. Quirke

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Map 1948. Wanapitei Lake area, Sudbury district, Ont. .. 35

INTRODUCTION

During the season of 1921, work was carried on in the region of lake Wanapitei for two primary objects; the mapping and classification of the Precambrian sediments, and the investigation of the ore deposits. The lake level has lately been raised, artificially, 16 feet, with the result that some islands have become peninsulas, and others have entirely disappeared; and the main shoreline itself has been locally affected, especially in the northeast part of the lake, where what was once a headland is now an island half a mile from the shore. A resurvey of the lake was consequently included in the season's work.

The writer was assisted by R. C. Emmons and W. L. Swanson, both of whom rendered intelligent and loyal service.

The main results of the season's work are: a corrected geographical and geological map; additional knowledge in regard to the ore deposits; and the elimination of the type occurrence of Wanapitei quartzite from the Sudburian series and its recognition as part of the Mississagi formation of the Bruce series.

GENERAL CHARACTER OF THE AREA

Wanapitei Lake area includes Rathbun, Aylmer, Mackelcan, and parts of Parkin, Norman, Capreol, Maclennan, Scadding, Fraleck, Telfer, and McConnell townships, and the old Indian reserve. The area covers only about 40 square miles, but is in a strategic position, lying, as it does, between the area of Map 179 A, Onaping sheet, issued in 1917, by W. H. Collins, and the area of Map 124 A, Wanapitei sheet, issued in 1914, also by Collins. It includes part of the area shown on Map 125, Sudbury sheet, issued in 1891, by R. Bell, and the northeast corner of the area represented on Professor Coleman's geological map of the Sudbury nickel region issued in 1905, by the Ontario Bureau of Mines.

The work done in this area thus connects the areal mapping of Coleman and Collins, and helps to bridge the gap between the detailed mapping of the Sudbury region and the detailed mapping of the Cobalt area which have been carried on by officers of the Ontario Bureau of Mines. It falls happily into the group of type areas by means of which Collins[1] worked out thoroughly the original Huronian area, showing that the subdivision of the sediments of Huronian age into the Bruce and Cobalt series holds good not only from Echo lake to Sudbury, but eastward beyond Wanapitei lake. Historically, it connects some of the latest work on the Precambrian sediments of Canada with some of the earliest, especially that of Alexander Murray in 1856.

[1] Collins, W. H., Geol. Surv., Can., Mus. Bull. No. 8, 1914.

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The area is easily accessible, being on the line of the Canadian National railway, between Capreol and North Bay. The station of Massey Bay within the area and 11 miles from Capreol, is only a few hundred feet from the top of Bowland bay on lake Wanapitei. The area is also easily entered from Crerar station, about 1½ miles from the southern end of Ashganing lake. The various canoe routes and trails are shown on the accompanying geological map (No. 1948).

There is a fairly good automobile road from Sudbury to Massey Bay. Motor boats and canoes can be hired either at Massey Bay or at the old Crystal mine between Bowland lake and Matagamishing lake.

A considerable amount of timber is still being driven down Wanapitei river and the lumbering tote roads are kept in good condition. So far as these roads and the water routes are concerned the area is fairly accessible, but off the roads travel is rendered difficult by the second growth which conceals wind falls and partly burned stumps and tree trunks, a result of the frequent fires that have laid waste the forests,[1] especially Scadding township where the most difficult geology seems to lie.

Physiographically the area is a particularly interesting example of highlands resulting from the erosion of synclines of the Huronian series of rocks, so that the highest hills are composed of the youngest formation, the peculiarly resistant Lorrain quartzite. These hills run parallel to the courses of Mountain creek and the upper Wanapitei river, coinciding for about 7 miles with a narrow tongue of quartzite which is bounded on the east and west by a less resistant slaty formation. In the southwest lies the most easterly rim of the Sudbury basin, the highest edge of which is formed by the resistant Trout Lake conglomerate.

Bedrock is well exposed to the north and east of lake Wanapitei except in the large sand-plains around the mouths of Post creek, Mountain creek, and upper Wanapitei river, and along the valley of Wanapitei river and its east branch. In the south and southwestern part of the area, the rocks are covered extensively by stratified sand and gravel which lie considerably above the present level of lake Wanapitei, and in the area southwest of Massey Bay station, show evidence of having been deposited at three different stages, about 50 feet apart in elevation. The top plain is a step above the middle one, which in turn seems to form an escarpment above the lowest. The level stretch of the highest plain is a very marked topographical feature. A thick glacial deposit extends across the area to the south of lake Wanapitei, but outside that zone the area shows abrasion and but little deposition due to glacial invasion.

GENERAL GEOLOGY

EARLIER WORK

The earliest report upon the geology about lake Wanapitei is found in the descriptions of Alexander Murray,[2] who in 1856 mapped certain water routes including Wanapitei river and lake and the large lakes between lake Wanapitei and Sturgeon river. Murray's section of the Huronian rocks found in the area follows in ascending order.

1. Fine-grained, green, siliceous slates, with the bands of green quartzite interstratified; also fine-grained slates, sometimes of a green tinge, and often bluish or black, weathering very black; occasionally some layers assume a reddish colour; copper pyrites and iron pyrites are frequently present in this division.

2. Slate conglomerate, the matrix always greenish in colour; sometimes it has a regular slaty structure, at other times it resembles a massive, fine-grained greenstone trap; it holds pebbles of white and red syenite in great profusion, with occasional masses of green, brown, and red jasper, rounded in form; associated with the conglomerate, and probably not far from the division No. 1 are green slates in very regular laminæ, cleaving with the bedding, and usually cut by parallel joints.

[1] Bell, Robert, Geol. Surv., Can., Ann. Rept., vol. IV, 1889-90, pt. F, pp. 7-8.
[2] Murray, Alexander, Geol. Surv., Can., Rept. of Prog., 1853-6, pp. 171-179.

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3. A band of limestone; its strata always appear very much disturbed, and it is in general associated with greenstone. The prevailing colour of the limestone when found in mass is a pale whitish-grey, sometimes passing into dark blue; the band is frequently brecciated, and often displays rough jagged edges, which appear to belong to layers of hornstone; parts of the band are indurated calcareous shale, and these occasionally contain fine-grained siliceous pebbles.
4. Slate conglomerate resembling the slate conglomerate on the other side of the limestone.
5. Green siliceous chloritic slates, with some tolerably strong bands of quartzite.
6. White and very pale, sea-green, close-grained quartzite, with beds of quartz conglomerate interposed, and layers of talco-quartzose slate, sometimes of a dark green colour, but more frequently a pale flesh-red. The pebbles of the conglomerate are chiefly small, white, opaque, rounded masses of quartz, but these are occasionally mixed with rounded masses of red and green jasper.

It is plain that Nos. 2 and 4 are descriptions of the Gowganda formation. No. 1 may be a composite description of the Serpent formation and certain phases of the Gowganda formation, the reddish-coloured slaty rocks being rather common in the Gowganda formation of this area. No. 3 is an excellent description of the Bruce limestone. No. 5 refers to the transition phase from Gowganda formation into Lorrain quartzite, and No. 6 is unmistakably of the Lorrain quartzite. Apparently Murray did not recognize the place and identity of the Mississagi quartzite, nor how to tell apart the Gowganda and Bruce conglomerates.[1] He reported syenites intruding contorted slates on the north shore of lake Wanapitei, but the rocks are actually Keewatin volcanic schists intruded by granite. He noted further that "the whole of the west and south shore of the lake displays the effects of a very high degree of disturbance, and slates, conglomerate, quartzite and greenstone, with brecciated limestone, come in strangely irregular juxtaposition." In spite of this irregularity (which Murray did not exaggerate) and the omission of the Mississagi formation, his section is surprisingly correct, especially when the briefness of his examination is considered.

Robert Bell[2] in 1921 issued a report on Sudbury mining district; in which he included a general description of the rocks exposed along the shores of lake Wanapitei and the water routes between Portage bay and Sturgeon river. An appendix contains certain notes by Professor H. G. Williams on the microscopical character of rocks.

Professor A. P. Coleman[3] has supplied most of the detailed information about Sudbury district. To him are due the description and definition of the Sudbury series, the classification of the deposits later known as the Whitewater series, and treatise on the Sudbury norite-micropegmatite sill and the nickel-copper ore deposits. He classified the formations of the Sudbury series as follows:

	Feet
Wanapitei quartzite	20,000
McKim greywacke	7,000
Copper Cliff arkose	2,000

Of chief interest in the present connexion is the Wanapitei quartzite, to which Coleman assigns a thickness of 20,000 feet, which he says becomes distinctly metamorphic near the intrusion of granite and extends eastward to near Wanapitei river south of Wanapitei lake.

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[1] Cf. Jour. of Geol., vol. XXIX (1921), pp. 470-472.
[2] Bell, Robert, Geol. Surv., Can., Ann. Rept., vol. V, 1889-90, pt. F, pp. 14-17.

[3] Coleman, A. P., Ont. Bur. of Mines, Ann. Rept., pp. 235-303, 1903.
Ont. Bur. of Mines, Ann. Rept., pt. 1, pp. 192-224, 1904.
"The Nickel Industry," Dept. of Mines, Can., Mines Branch, Bull. 170, pp. 3-11, 1913.
"The Precambrian Rocks North of Lake Huron, with Special Reference to the Sudbury series," Ont. Bur. of Mines, Ann. Rept., vol. XXIII, pt. 1, pp. 204, 236, 1914.
"The Sudbury Series and Its Bearing on Precambrian Classification," Congrès Geol. Inter., XII Session, 1914. Compte-Rendus, pp. 337-398.
Problems of American Geology, pp. 81-161, 1915, etc.

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C. R. Van Hise and C. K. Leith[1] maintained that inasmuch as the conglomerates, greywackes, and quartzites of the Sudbury region contain limestones in the Wanapitei area, immediately east of Sudbury, they are equivalent to the lower division of the original Huronian district proper. This contention has been verified in part.

W. H. Collins[2] in 1912 studied in detail an area south of lake Wanapitei, and examined less extensively other places about the lake. He reported that the Sudbury series includes a white, hard, feldspathic quartzite, thousands of feet thick, intruded by granite, and that the Cobalt series of the Huronian division is unconformable upon the Sudburian and younger than the granite. The Cobalt series is reported to consist of basal conglomerate, greywacke, and limestone 10-15 feet thick, which grades into greywacke and finally into quartzite.

STRATIGRAPHY

The Precambrian of the Wanapitei Lake area is represented by a rather wide range of rocks. On the southwestern side of the lake, between Blueberry island and Bowland bay, numerous outcrops of Keewatin schists the oldest rocks in the area—are intruded by Precambrian granites, and overlain unconformably by the Bruce and Cobalt sediments of the Huronian. The Bruce series is represented by the Mississagi quartzite, Bruce conglomerate, and the Espanola and Serpent formations; the Cobalt series by the Gowganda formation and Lorrain quartzite. This is —although not recognized in earlier reports—almost the complete succession of sediments in the classical Huronian area near Sault Ste. Marie. In the southwestern corner there is well exposed for about 8 miles the northeastern lower contact of the Sudbury norite. The upper contact of the norite, poorly exposed for several miles, lies, with the Trout Lake conglomerate, underneath the Onaping tuff, both of the Whitewater series. Here, as elsewhere in Sudbury district, the relation of the Whitewater series to the Huronian rocks is unknown.

[1] Van Hise, C. R., and Leith, C. K., "Precambrian Geology of North America," Bull. 360, p. 439, 1907.

[2] Collins, W. H., Geol. Surv., Can., Sum. Rept., pp. 189-195, 1913. "Geology of a Portion of Sudbury Map-area, South of Wanapitei Lake, Ont."

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Table of Formations

Quaternary.....	Pleistocene.....	Sand, gravels, local lake clays, morainal deposits and glacio-fluviatile derivatives.
	Great unconformity	
Huronian	Keweenawan?	Granite intrusions of post-Bruce and possibly of this age. Sudbury micropegmatite-norite sill. Diabase and norite intrusions.
	Whitewater series	Chelmsford sandstone (not represented). Onwatin slate (not represented) Onaping tuff 4,000? feet Trout Lake conglomerate 500 feet Relations unknown—stratigraphic hiatus.
	Cobalt series	Lorrain quartzite 5,000? feet Gowganda formation 3,500 feet
		Erosional and minor structural unconformity.
	Bruce series	Serpent quartzite 800 feet (partly eroded) Espanola formation Greywacke 400 feet Limestone 200—600 feet [1]Bruce conglomerate 800? feet Mississagi quartzite and basal conglomerate 5,000? feet
		Great unconformity
Pre-Huronian	Batholithic intrusives	Granite
	Schist complex (Keewatin)	Volcanic schists, and jaspilyte, "banded iron formation."

PRE-HURONIAN SCHIST COMPLEX (KEEWATIN)

In Wanapitei Lake area the Keewatin schists are well-banded, and are apparently largely of fine volcanic tuff. Some of these schists may be composed in part of sedimentary material, not necessarily of direct igneous origin. On the west side of Massey bay a green greywacke or tuff, with no perceptible bedding, weathers with a pale chipped surface. Farther north along the shore a very well-bedded tuff which because of its bedding looks like a sedimentary greywacke, shows on close examination its ashy composition. This formation is cut in many places by smoky quartz veins. In the extreme southeastern corner of the area and in the neighbourhood of Crerar station, just beyond the area to the east, the stratiform character of these pre-Huronian rocks is markedly displayed. Just north of the old Indian reserve, the schists are less schistified and resemble metamorphosed lavas. They include thin formations of a banded material within which are banded siliceous ferruginous phases, the so-called jaspilyte[2] or iron formation, common to the Keewatin schists of nearly every district north of lake Huron. Miller has described this occurrence of iron formation,[3] and nothing need be added here, except that many claims for iron have been staked in Rathbun township. The most promising are located in lot 24, concession VI, but the writer saw nothing likely to be of value.

[1] Includes those formations previously mapped as Sudbury series on Map 124A. Includes the Ramsay Lake conglomerate of Falconbridge township as mapped by A. P. Coleman.

[2] Van Hise, Bayley, and Smith, U.S. Geol. Mono. No. XXIII, p. 362.

[3] Miller, W. G., Ont Bureau of Mines, 1901, p. 177.

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PRE-HURONIAN GRANITE

The granite intruding the Keewatin schists occurs along the west shore and about the islands near the west side of lake Wanapitei. It is of alaskite type, of fine, granular texture, generally free of pegmatitic varieties or other evidence of magmatic differentiation. Professor G. H. Williams[1] described some specimens from this locality as including orthoclase phenocrysts in a groundmass of oligoclase, quartz, and biotite, and subordinate amounts of magnetite, pyrite, allanite (?), and alteration products of these minerals.

BRUCE SERIES

Mississagi Formation

The contact between the base of the Huronian series and the underlying schists and granite is exposed in very few places, but opposite the diabase point in Bowland bay may be seen the unconformable contact between a basal conglomerate and an underlying body of schists which contains an intrusion of acid rock. The contact follows close to the shore for nearly 3 miles, but the relations are obscured by intrusions of diabase, and by high water. This conglomerate may well be part of the basic conglomerate of the Mississagi formation. The contact continues north to the schists near the Indian reserve, but poor exposures make it difficult to analyse. There is in some places a conglomerate close to the schists, but it is doubtful whether it is actually unconformable upon them; it may be a faulted contact, though this possibility seems unlikely. In the extreme southeastern corner of the map-area a dark conglomerate is exposed between the schist at Crerar and quartzite on the north. Among these localities there is certainly no question about the character of the contact on Bowland bay, nor is the relation in other places seriously in doubt. In general it may be said that the base of the Huronian is a dark-coloured quartzitic conglomerate.

Above the conglomerate, which is less than 50 feet thick, is a thick quartzite member which is most probably from 3,000 to 5,000 feet thick. The quartzite, very well exposed on the east side of Bowland bay, runs with diabase interruptions to Southeast bay by way of Howie and Oak islands both of which give excellent exposures, and continues to the north of the Indian reserve, composing most of the peninsula and the islands between Bowland bay and Outlet bay. It outcrops again from Outlet bay to Southeast bay, and upon Ashganing lake, and thence passes to the southeast beyond the borders of the area.

Inasmuch as the conglomerate member and the quartzite are together correlated in this report with the Mississagi formation as described by Collins,[2] whereas Coleman[3] called this quartzite the Wanapetei quartzite and placed it in the pre-Huronian, Sudbury series, it is deemed advisable to describe in detail some of the exposures of these rocks.

On the west side of Massey bay, lot VIII, concession IV, syenitic rock intrudes greenstone schists containing many smoky quartz veins, and both are overlain unconformably by a basal conglomerate, here correlated with the Mississagi formation. The syenite is greatly kaolinized, apparently by prolonged weathering. This weathering must have been previous to glacial times at least, because other glaciated feldspathic rock surfaces are not appreciably kaolinized, and apparently it represents the work of the elements previous to deposition of the basal conglomerate. The schist is much chloritized so that its original character is indistinguishable. The overlying conglomerate contains relatively few elongated pieces of schist and relatively many rounded pebbles and boulders of dark chert or smoky quartz. The basal layer of conglomerate is about 2½ feet thick, and is overlain by 6 feet of coarse

[1] Williams, G. H., Geol. Surv., Can., Ann. Rept., vol. V, app. I, 1889-90, p. 59 F.
[2] Collins, W. H., Geol. Surv., Can., Mus. Bull. No. 8, 1914.
[3] Coleman, A. P., Ont. Bureau of Mines, Ann. Rept., vol. XXIII, pt. 1, 1914, pp. 213-214.

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arkose, followed by 7 feet of conglomerate containing many smoky quartz pebbles and cobbles and a few boulders of granite up to 8 inches in diameter. Further exposures are covered by the high water of the lake.

On the shores of the peninsula between Massey bay and Outlet bay, the Mississagi quartzite strikes in general about north 10 degrees east and dips about 12 degrees south, although there are minor rolls where the dip is reversed. The rock is crossbedded in places, but in general well-bedded every 2 or 3 feet. It weathers a pale greenish yellow, but on fresh surfaces it is pink. It is an arkose, with many clear quartz grains, some being one-tenth inch in diameter. In places there are small inclusions of mudstone, in others streaks of fine-grained, siliceous greywacke. In general it is a fairly coarse, crossbedded arkose containing rounded quartz grains and kaolinized feldspars, together with certain streaks 2 inches thick of conglomerate carrying pebbles up to 2 inches in diameter, of quartz and granite.

At the north end of Howie island the quartzite is decidedly reddish: at the south end it is pinkish, but between the pink below and the red above the quartzite is pale greenish yellow. Near the north end of Oak island is a greywacke phase showing ripple-marks, some mud-cracks, well-marked dark bedding, greywacke streaks, also small lenses of sand in the dark greywacke.

Just west of the mouth of Mountain creek the Mississagi quartzite is well bedded, varying from fine-grained, pale weathering arkose to greenish, sandy rock characteristic of the Mississagi formation. Quartz and feldspar sand alternate in places causing a characteristic appearance of lining on weathered surfaces, but the formation contains an unusual amount of recurrent conglomerate bands with highly siliceous matrix, carrying chiefly quartz pebbles up to 3 inches in diameter. The beds are slightly overturned, as is shown by the position of the overlying Bruce conglomerate and by the position and shape of the crossbedding lines. At a distance of 15 chains from the point opposite the neighbouring island is a fault line bearing south 15 degrees west, which brings the limestone formation next to the base of the Mississagi formation.

On the south side of the outlet of Ashganing lake is an outcrop of quartzite, which is correlated with the Mississagi formation, being highly vitreous and granular in texture, dark grey on fresh faces, with many reddish streaks and stains, cut by many quartz veinings. It has the general appearance of being near a younger granitic intrusive rock, although no such granite outcrops nearby. However, quartzite correlated with this formation is intruded by granite in the map-area immediately south of Wanapitei Lake area (Map 130).

Bruce Conglomerate

Overlying the Mississagi quartzite, as in the Huronian area, is a massive conglomerate, which must be the Bruce, which in this area is apparently more than 1,000 feet thick. It differs in no important way from the Bruce conglomerate along the north shore of lake Huron, where it is dark green, very siliceous in certain of its phases, rather remarkably consistent in character, and contains pebbles and a few boulders of granite and greenstone with still fewer pebbles of quartz and metamorphic rocks. No boulders of clearly sedimentary origin were discovered in the Bruce conglomerate, though more careful search might discover some.

Other parts of the North Shore region, notably Espanola, contain the Bruce conglomerate distinctly stratified and including layers of quartzite and parts without any visible stratification. This is not true apparently of the Bruce conglomerate in the Lake Wanapitei area,[1] for it shows no bedding. Certain minor features are persistent, such as the peculiar pale bluff colour of the bare, weathered faces of the rock and the peculiar way in which, under deformation, the matrix of the conglomerate

[1] Cf. Collins, W. H., Geol. Surv., Can., Sum. Rept., 1913, p. 193. The Cobalt conglomerate here referred to by Collins is really the Bruce.

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pulls away from the pebbles in the direction of the greatest elongation of the rocks, thereby leaving a cavity which in some cases is filled with pyrite, in other cases with calcite, or in a few cases is empty. The siliceous character of the matrix, which contains many small fragments of quartz, is another distinction noted in other areas. This discovery of the Bruce conglomerate extends its known distribution from Sault Ste. Marie not only to Sudbury district, but beyond it in an easterly direction.

Near the railway bridge across Wanapitei river, in a railway cut, is a very siliceous conglomerate with greywacke matrix carrying angular as well as rounded pebbles and boulders of granite, schist, quartz, and apparently, quartzite. Where weathered, the surface is rough with some pebbles weathered out of the matrix (the matrix of the Gowganda conglomerates is commonly more readily weathered than the included pebbles). The matrix resembles that of the Bruce conglomerate in Espanola area, in that the competent rhyolite pebbles are loosened from their surroundings by deformation of the incompetent matrix, and the matrix is characterized by so-called grits, or little quartz grains of pin-head size, but not by the small rock particles that characterize the matrix of the Cobalt conglomerate.

About half-a-mile west of Mountain creek is clear evidence of the intermediate position of the Bruce conglomerate with respect to the underlying Mississagi quartzite and the Bruce limestone above. The diagnostic characteristics of the formation may, almost all, be seen, and a peculiar, pale salmon colour on weathered surfaces that, so far as the writer knows, appears in no other conglomerates of the Precambrian series.

Along Wanapitei river, about 2 miles below the outlet of the lake, the conglomerate is metamorphosed into a spotted schist, much as it is in the Espanola area, and about the southeastern part of lake Penage. Another good exposure of the (Bruce) conglomerate, showing its transition into the overlying limestone, may be seen on the east side of the rapids of Wanapitei river beside Portage island. Similarly its relations to the Mississagi formation below and the limestone above may be seen clearly at the southwest side of the large point in Ashganing lake.

The relations of the Bruce conglomerate in Wanapitei Lake area are different from those in the Geneva area, northwest of Sudbury,[1] where the Bruce conglomerate is lacking, and the Mississagi formation grades directly without unconformity into the Espanola formation. Apparently in spite of its great east-west distribution, the (Bruce) conglomerate was not as widely distributed as either the formation above it or the one below it, but at lake Wanapitei it is well and characteristically developed and exposed in many places.

Espanola Formation

The Espanola formation in Lake Wanapitei area consists of limestone and greywacke, or indurated silt, lying upon the Bruce conglomerate with a very thin transition member. The limestone member, corresponding to the Bruce limestone of the original Huronian area, must be at least 200 feet thick on Portage island, the first large island below the dam on Wanapitei river,[2] but seems to be not more than 100 feet thick in other disconnected, small exposures. On Portage island, the Espanola formation includes, above the limestone, several hundred feet of thin-bedded, slaty argillite and greywacke which correspond exactly in character and position with the Espanola greywacke of the Espanola area. It even contains ripple-marks and mud-cracks and fine, interbedded layers of quartzite and greywacke, which could not be distinguished from specimens taken from Espanola area. However, the exposure of greywacke above the limestone is confined in this area to the small strip between the Canadian Northern railway and Wanapitei river near Portage island.[3]

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[1] Geol. Surv., Can., Sum. Rept., 1920, pt. D.

[2] Cf. Murray, Alexander, op. cit., p. 296.
Bell, Robert, op. cit., p. 14 F.
Collins, W. H., Geol. Surv., Can., Sum. Rept., 1913, p. 193.

[3] Collins, W. H., Geol. Surv., Can., Sum. Rept., 1913, p. 193.

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The limestone occurrences are of greater importance in correlating these sediments with the formations of the original Huronian area, as was clearly recognized by Van Hise and Leith, and especial value attaches to the discovery on the northwest shore of lake Wanapitei. Owing to this discovery the Bruce age of the associated rocks was recognized, and the distribution of the series thereby greatly extended in a direction not before suspected. A fault about half-a-mile west of Casselman's camp on Mountain creek cuts off good exposure of vertical limestone from the Gowganda conglomerate on the east, and apparently conformably upon Bruce conglomerate to the west. The limestone is faulted against the Mississagi quartzite near the lake shore about a half mile farther south (*See* page 40). At this place the faulted zone contains a jumble of conglomerate, quartzite, greywacke, limestone, and diabase. Much of the limestone appears to have recrystallized and formed veinlets and masses of white calcite.

Along Wanapitei river below the outlet of the lake numerous exposures of limestone bear out the common characteristics of the limestone elsewhere along the north shore of lake Huron. The rock weathers buff to red, and develops a rough-lined surface due to the unequal weathering of the interbedded calcareous and greywacke streaks. On fresh surfaces it is blue grey, in metamorphosed phases being marble and elsewhere highly siliceous, calcareous greywacke. The rapids at Portage island follow the strike of the limestone which is about 200 feet thick, exceptionally well-exposed and very little crumpled, relatively speaking, although in a vertical position. The gradation through about 2 feet, from Bruce conglomerate through greywacke into the limestone, can be seen; and beyond the limestone comes typical Espanola greywacke grading through the usual type of greywacke quartzite into a dark coloured, but light-weathering quartzite, which is the Serpent. This Espanola formation has mud-cracks, ripple-marks, and intraformational conglomerates made up of the dried mud shells that formed during emergence, and were covered again by rising water. Thus the relations of the limestone to the formations both above and below are clearly gradational. This highly critical, conformable succession of conglomerate, limestone, greywacke, and quartzite has not previously been reported as the Bruce series from any area east of Sudbury.

Serpent Formation

The Serpent formation has been recognized only in the small area parallel to Wanapitei river, stretching on both sides of the Canadian Northern railway for about a mile eastward from the station of Spaidal, and in a very small area in lot 2, concession I, Aylmer township. In most places along the north shore of lake Huron the Serpent formation is arkosic quartzite. A great thickness is reported from some localities, especially the area about the western end of lake Penage. The formation is characterized by an unusual development of conglomerate and grit in the Geneva map-area. It is impossible to tell how thick the Serpent formation originally was in Lake Wanapitei area because the top is nowhere recognized, and its relations to the surrounding rocks are obscured by drift in the south and by faults in the north. The formation is a dark quartzitic greywacke, characterized by streaks of ripple-marked and mud-cracked greywacke within beds of pale green quartzitic arkose. It is evidently conformable above the Espanola greywacke formation and seems to correspond pretty closely in character to the lower part of the Serpent formation in the original Huronian area.

COBALT SERIES

Gowganda Formation

Collins,[1] in his report on the Onaping area, classified all of the local sediments of Huronian age, older than the Lorrain quartzite, under the name Gowganda formation and mapped[2] the limestone and all the conglomerates as part of the Gowganda

[1] Collins, W. H., Geol. Surv., Can., Mem. 95, 1917.
[2] Map 124A, Wanapitei, Sudbury district, Geol. Surv. Can.

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formation. Subsequently, however, work carried on by Collins[1] in the Precambrian of the original Huronian area led him to suspect that some of the rocks mapped on Map 124A are in part, if not altogether, of the Bruce series, as indeed this season's work has made certain. The map (No. 1948) accompanying this report restricts the Gowganda formation to those phases of the Cobalt deposits which lie below the easily recognized, characteristic Lorrain quartzite and which are unconformable upon the Bruce series; and shows the Gowganda formation is well developed.

The Gowganda, which is generally referred to as the "Cobalt conglomerate," is the formation to which Coleman[2] first ascribed a glacial, and for which W. L. Whitehead[3] has recently suggested a fluvial, origin. Whitehead's conclusion has been vigourously criticized by Coleman[4] who points out, among other things, that the well-known bedding referred to by Whitehead is due probably to standing waters and not to rivers. Whitehead seems to have ignored most of the many previous discussions of the subject that preceded his own, which was based apparently on one season's work in the Cobalt district, an area of about 6 square miles. Other workers have published the results of observations made during many seasons over areas aggregating thousands of square miles. Nevertheless, Whitehead's paper is useful because it emphasizes once[5] again that not all but only parts of the Gowganda formation appear to be of glacial origin. There are hundreds of feet in the formation where it is useless to look for a clear suggestion of glacial origin, and if Whitehead's paper was based on such parts of this formation, he would find little to support the contention that the formation is of anything but deposition from running water, being well sorted, including alternating bands of arkose, slate-like rock, and gravelly lenses, which may well have been deposited partly in running and partly in standing water. It is probably no exaggeration to say that the greater part of the Gowganda formation provides no evidence of a glacial origin, as will be clear from a study of detailed sections[6] of the formation. On the other hand, certain members of very finely laminated argillite or greywacke carry scattered pebbles and small rounded cobbles which must have been deposited by some agency other than that which deposited the matrix. The natural assumption is that this other agency was floating ice. Again, there are other bands, within the Gowganda formation, composed of unsorted bouldery conglomerate. These bands are associated with the beds of finely laminated greywacke which carry pebbles, and within such bouldery layers are striated and deangulated rock masses which in every way appear to be of the same character as those produced by recent glaciation. Thus a general study of the whole Gowganda formation gives an impression different from that gathered from most reports, and a good deal more inclusive than that given by Mr. Whitehead.

The Wanapitei area sheds little new light on the intricacies of the Gowganda formation, and descriptions from certain localities will serve as types of its different phases. A section across the nearly vertical Gowganda beds on both sides of Mountain creek reads as follows, starting about one-half mile west of Casselman's camp on the creek and going diagonally across the formation northeastward, from near the base of the formation upwards:

1. Massive, bouldery conglomerate containing boulders up to 14 inches in diameter, the matrix being slaty near the base, becoming siliceous higher up.
2. Siliceous greywacke, bedded like quartzite but containing pebble streaks.
3. Massive greywacke with very irregularly shaped granite pebbles and cobbles 8 inches in diameter.

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[1] Personal communication.

[2] Coleman, A. P., Rept. Ont. Bureau of Mines, vol. XIV, 1905, pt. 3, p. 129.

[3] Whitehead, W. L., Econ. Geol., vol. XV, 1920, p. 105.

[4] Coleman, A. P., Econ. Geol., vol. XV, 1920, pp. 539-541.

[5] Wilson, M. E., "The Cobalt Series: Its Character and Origin," Jour. Geol., vol. XXI, 1913, pp. 121-141. *See* particularly pp. 133-134 and 140.
Collins, W. H., Geol. Surv., Can., Mem. 95, 1917, pp. 80-84.
Quirke, T. T., Geol. Surv., Can., Mem. 102, 1917, pp. 43-49; Sum. Rept., 1920, p. 12 D.

[6] For detailed sections *see*
Collins, W. H., Geol. Surv., Can., Mus. Bull. No. 8, 1914
Quirke, T. T., Geol. Surv., Can., Sum. Rept., 1920, pp. 14 D-15 D.

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4. Siliceous, massive greywacke, and banded greywacke with scattered pebbles.
5. Gradation into massive, siliceous greywacke.
6. Banded greywacke with streaks of quartzite up to one inch wide.
7. Massive pebbly conglomerate with matrix of dark green argillite, carrying granite pebbles and boulders up to 10 inches in diameter scattered irregularly and sparsely. The pebbles become small, few, and irregular in shape higher up the formation, the matrix weathering with a peculiar, chipped-out surface like a ripple-marked outcrop characteristic of certain phases of the Gowganda[1] formation.
8. Gradation into a finely laminated slate-like rock free of quartzitic material or pebbles, nearly vertical in position, over 200 feet wide across the strike.
9. Gradation into more massive greywacke carrying pebbles scattered irregularly through it, being less than half the Gowganda formation.

Again, at "Camp 3" in the northeastern part of the area is a typical section of the Gowganda formation lying just below the transition phase into the Lorrain quartzite. It is a coarse bouldery conglomerate with a massive greywacke matrix containing many inclusions of alaskitic granite and schist. The inclusions are of irregular shapes scattered 2 or 3 feet apart and about 8 to 10 inches in diameter—one noted was 3 feet by 2 feet. The matrix is green and argillite-like, containing many small chips and unrounded fragments of granite. This is considered to be typical tillite of the Gowganda formation.

A very well-bedded phase of the upper part of the formation is exposed along the shore of East bay, lake Wanapitei, and in the narrows that separate the west arm from the remainder of Kukagami lake. It is made up of definite, resistant beds of quartzitic greywacke, from 3 to 6 feet thick, separated by streaks of greywacke with or without pebbles. Many of these greywacke beds weather into the appearance of red slate, which is probably the rock referred to by Murray in his formation No. 1 (*See* page 35). This phase is overlain by massive conglomerate, which may be seen plainly at the south end of Matagamisi lake, along MacLaren creek, on the southern shores of Kukagami lake, and near "Camp 3," as noted above. The well-bedded phase recurs near the top of the formation, being especially prominent where the strike of the rock bears nearly parallel to the upper course of the East branch, giving rise to a succession of cliff-fronted hogbacks facing westward.

The Gowganda formation of Lake Wanapitei area, therefore, consists in general from the base upward of the following phases:

1. A roughly stratified basal conglomerate member.
2. A very well-bedded, thinly laminated argillite, which grades upward into well-bedded, quartzitic and red slaty greywacke and pebbly conglomerate.
3. By the addition of boulders and cobbles and by the loss of definite bedding, this becomes a massive greywacke, bouldery conglomerate.
4. A repetition of the quartzitic and greywacke well-bedded phase, which grades finally into the Lorrain quartzite.

Lorrain Quartzite

Immediately above the Gowganda formation, after a gradation of several scores of feet, the dark greywacke of the Gowganda formation gives place to a singularly pure, pale green quartzite, which outcrops in tongues in the northern part of the area, one stretching from the southeast corner of Fraleck township to the mouth of upper Wanapitei river, and the other extending from a point about one-half mile east of the East branch, westward almost to the northeast corner of the area and southeastward to the northern division of lake Kukagami. This quartzite constitutes the range of high hills—clearly visible from Massey Bay—to the north of lake Wanapitei. The northern tongue being a sharply folded syncline is now a precipitous hill; the northeastern tongue is a much more gently-folded syncline not nearly so lofty nor so rugged as the northwestern, which is bounded on nearly every side by precipitous breaks that make it very simple to map. The lines of contact together with the direction of strike, in general, are persistent over considerable distances, whereas in the northeastern tongue unequal erosion of the surface has resulted in an irregular line of contact all the more pronounced on account of the relatively low dip of the formation. The quartzite is characterized by streaks of small quartz and jasper

[1] Geol. Surv., Can., Sum. Rept., 1920, p. 14 D.

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pebbles which seem to recur throughout the whole formation everywhere from the neighbourhood of Sault Ste. Marie to the Cobalt district, where it was first called Lorrain arkose.[1] Inasmuch as it is the youngest known formation of the Huronian series, it is found solely in the synclines where it is commonly metamorphosed into a green mica schist of aged appearance.

Collins[2] reports the lack of jasper pebbles in the Wanapitei area, but they were found this season although they are scarcer than in most Lorrain localities. He reports the presence of an overlying cherty quartzite which was not recognized by the members of this party.

Nature of the Bruce-Cobalt Contact

Nowhere in Wanapitei Lake area, except possibly on lake Ashganing, was a good exposure of the contact at the base of the Cobalt series with the underlying rocks discovered. In the northwestern part of the area the Cobalt series rocks are separated from the Bruce formations by a zone of faulting and diabase intrusions, and between lakes Wanapitei and Ashganing the contact continues. However, on the east side of the great peninsula of lake Ashganing there is an erosional unconformity which is certainly beneath most if not all of the Gowganda formation, and apparently above what is either a quartzitic streak in the Bruce conglomerate or the Mississagi quartzite. Upon the peninsula west of this contact there are two synclines containing the Espanola limestone, on both sides of which the Bruce conglomerate is repeated, but there is neither Serpent quartzite, nor any but a very little of the Espanola greywacke preserved above the limestone. Apparently the Bruce series was folded into a small synclinorium at this place during the pre-Cobalt period of erosion and previous to the deposition of the Gowganda formation. The unconformable character of the contact is indicated by the existence of a considerable thickness of the Serpent formation between Wanapitei river and Spaidal station, whereas the Serpent formation was found nowhere else under the Cobalt series except for a few hundred square feet west of Casselman's camp, as before noted. In these latter places the Serpent formation must have been eroded before the deposition of the Gowganda formation.

There are certain other indications that there may have been folding movements between Bruce and Cobalt times. For instance, there seems to be a marked contrast in the degree of folding of the formations of the two series in the southeastern part of the area; the Cobalt formations dip generally less than 45 degrees, whereas the Bruce formations are nearly vertical. However, in the northwestern part of the area there is not such an obvious contrast in this respect. This is, perhaps, due to the fact that the locus of post-Huronian mountain-building lay towards the southwest.[3] Certain it is that the Cobalt series is more nearly flat-lying in the northeastern part of the area than farther south and west.

Along the north shore of lake Huron there is a profound erosional unconformity between these two series of the Huronian division.[4] Previous to the deposition of the Cobalt formation thousands of feet of the Bruce series were eroded over large areas west of Sudbury, leaving a region having considerable relief, possibly a deeply dissected plateau area. This appears to have been induced by epirogenic movements and not by orogenic disturbances, for no discordance in excess of 10 degrees has been noted between the Cobalt series and the Bruce series west of Sudbury. It is well known, however, that most periods of earth movement have included simultaneously epirogenic movements of large areas and orogenic uplift of relatively small areas. Is this not

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[1] Miller, W. G., Fourteenth Ann. Rept., Ont. Bureau of Mines, pt. II, 1905.
[2] Collins, W. H., Geol. Surv., Can., Mus. Bull. No. 8, 1914, p. 22.
[3] Geol. Surv., Can., Mus. Bull., No. 22.
[4] Collins, W. H., Geol. Surv., Can., Mus. Bull. No. 8, p. 25, 1914.
Quirke, T. T., Jour. Geol., vol. XXIX, 1921, pp. 470-471.

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likely to have been the case at the end of the Bruce epoch and may not the locus of the more intense earth movements include Wanapitei area? This view is perhaps supported by the fact that the sedimentary formations south of lake Wanapitei are intruded by granite.[1] These sediments were at first taken to be pre-Huronian or Sudburian in age, but it is now certain that they are of Bruce age.[2] Nothing further was learned last summer regarding the age of these post-Bruce acid intrusions. Although the Cobalt formations of the area are not intruded by granite, it was not ascertained that they overlie the acid intrusives unconformably; consequently the evidence is in no way conclusive. In the Killarney[3] area the intrusions are known to penetrate the Cobalt series, and in the Geneva[4] area syenitic granite appears to penetrate Cobalt as well as Bruce formations.

In general we do not know that there was a period of mountain-building accompanied by igneous intrusion after the deposition of the Bruce series, followed or accompanied by a long period of erosion, previous to the deposition of the Cobalt series, and the writer feels impelled to state this as a working hypothesis which has developed as one of the results of this season's work. In any case it is certain that a period of uplift and long erosion intervened between the deposition of the youngest known formation of the Bruce series and the accumulation of the Cobalt deposits.

WHITEWATER SERIES

The formations of the Whitewater series lie in the extreme southwest corner of the area, and are largely covered with sand and gravel. The Trout Lake conglomerate at the base of the series is a remarkable formation quite unlike any of the Huronian conglomerates. It is very siliceous and is composed largely of small pebbles and irregularly shaped fragments of quartzite, chert, quartz, granite, and greywacke. No boulders more than 10 inches in diameter were seen, and the only observed individual of that size was a very irregularly shaped piece of quartzite. The formation is a rubbly conglomerate, composed of rocks of many kinds and shapes, and nearly all less than one-half inch in diameter. There seems to be little variation in its character from top to bottom, except perhaps that the upper part is better sorted. At the base, especially, it appears to be massive; no bedding planes or distinct lens or layers of gravel or greywacke were seen. The structural position of the formation is assumed from the distribution of its outcrops. It forms a long, almost straight hogback facing northeastward, and constitutes in a very striking manner part of the edge of the Sudbury basin. Within this ridge to the southwest lies a sand-plain, in which are certain outcrops of well-bedded, grey volcanic tuff which has been called by Coleman the Onaping tuff. Little can be added to previous description of these formations.[5] Neither the Onwatin slate nor the Chelmsford sandstone outcrops within the Lake Wanapitei area. The Whitewater series slopes gently towards the interior of the basin, and is separated from the Huronian formations by a band of norite, which constitutes the basin, as well as by older granites, and glacial deposits.

KEWEENAWAN INTRUSIVES

Most important of the later irruptives is the Sudbury norite and micropegmatite, just referred to, which stretches from Ella lake to the sand-plains in the south. Under the sand deposits its distribution could not be traced, but doubtless it persists. This formation intrudes the Whitewater series and seems to lie upon the pre-Huronian granite and green schists. At its northern contact numerous prospects and developments show the concentration of pyrrhotite in considerable amount in

[1] *See* page 36.
[2] Collins, W. H., personal communication.
[3] Collins, W. H., Geol. Surv., Can., Mus. Bull. No. 22, 1916.
[4] Quirke, T. T., Geol. Surv., Can. Sum. Rept., 1920, pp. 16-17 D.
[5] Coleman, A. P., "Problems of American Geology" (1915), pp. 141-144.

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certain places. Diamond drilling has been carried on elsewhere along the outer edge of the norite, and exploration in general seems to have been thorough.

The contacts of other types of diabase, which are distributed in large masses from the northwest to the southeast of the area, have not been as well examined, although there are several prospects about the shores of lake Wanapitei and a few claims that have been worked for gold. The most important of these, probably, are the Bonanza on lake Bonanza, and the Crystal between Bowland lake and lake Matagamisi. There are, in addition to these, which were not financially successful, certain claims worth consideration. Visible gold occurs in many locations on the east shore of lake Kukagami; near Massey Bay; to the east of the southeast bay of lake Wanapitei; and doubtless in other places. The gold occurs in quartz veins in association with iron pyrite in some cases and in other cases with the addition of galena and carbonate. So far as known all the veins are near the contact of the diabase, and—in one promising locality at least—in the neighbourhood of a major fault which is near the contact of the diabase.

PLEISTOCENE FORMATIONS

There are considerable deposits of glacial origin in the southern part of the area, and wide sand-plains in the valley of the upper Wanapitei river and along the East branch, extending for several miles along the north shore of the lake, where they seem at first glance to represent deposits formed when the lake level was much higher than it is today. But this apparently flat sand-plain is a good deal lower near the old Indian reserve than it is along the valley of upper Wanapitei river, where the sand bluffs rise between 20 and 30 feet above the present river level. And the fact that the sand-plain is characterized by numerous ridges and other minor irregularities shows that something besides deposition on a lake bottom occasioned the accumulation of sand. The gradual rise from south to north indicates that a stream from the north deposited sand in a basin partly filled by the waters of lake Wanapitei. If the present level of the lake were raised, the water would escape through Portage bay and Bowland lake and through lake Matagamisi to Sturgeon river, hence, theories based on the assumption that the ancient lake level was much higher than at present are not very convincing. Various depressions of the kettle-hole type near Higgins bay are clearly deposits of an ice-sheet. Some of these kettle-holes are only slightly above the present lake-level, and would certainly have been buried beneath lacustrine deposits if the level of the lake had been high enough to cause the deposition of the northern sand-plain. It seems, therefore, that lake Wanapitei has never been much higher than now, and, as already mentioned, the present level has been raised artificially 16 feet. The rather curious high sand and gravel plateaus south of Massey Bay terminate abruptly in the manner of an embankment or an artificial fill, and probably represent levels of sub-glacial deposition. Their erratic distribution and varying heights seem incompatible with any theory of origin dependent upon change of widespreading water-levels. Standing waters undoubtedly played their part, as is evidenced by the stratified lake clays containing boulders near the railway bridge across Wanapitei river;[1] and although such lakes are commonly associated with the edge of ice-sheets, this does not negative the idea that the widespread, sorted, sandy material is of sub-glacial origin.

CORRELATION

Ramsay Lake Conglomerate

There are two areas of massive conglomerate, one at Ramsay lake near Sudbury, and one in Falconbridge township, which have been mapped under the local name of Ramsay Lake[2] conglomerate because the correlation of these formations was in doubt.

[1] Collins, W. H., Geol. Surv., Can., Sum. Rept., 1913, p. 195.

[2] Coleman, A. P., "The Nickel Industry," Ont. Bureau of Mines, Rept. of Mines, Can. Mines Branch, Bull. 170, pp. 6 and 8, 1913, and map of Sudbury Nickel region, Ont., 1905.

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Coleman[1] thought that both these areas were representatives of the Cobalt conglomerate, and, at one time, Collins[2] agreed with him at least as far as the area in Falconbridge is concerned. This was also the opinion of Miller and Knight,[3] although they correlated both Cobalt and Ramsay Lake conglomerate with the Whitewater series under the name Animikean.

The writer visited the Falconbridge area, which lies a few miles south of the Lake Wanapitei area and is shown on Collins' Map 124A, and was able to identify the following part of the Bruce succession west of the gold claims alongside the diabase in lot 6, concession II: Bruce conglomerate, Bruce limestone, Espanola greywacke, Espanola limestone, a fault zone followed by Mississagi quartzite. In lot 5, concession III, the Mississagi quartzite underlies Bruce conglomerate, which is continuous with that in contact with the limestone. These outcrops represent an eroded series of folds wherein the structural position of the massive Bruce conglomerate is made clear by the position of the overlying limestone and underlying quartzite. The conglomerate—as both Collins and Coleman note—is massive and generally without indigenous indications of its position, and both considered it to be unconformable upon the almost vertical quartzite and limestone. However, later work has shown conclusively that the Bruce succession is quartzite, conglomerate, limestone, and it may be recognized by this order of outcropping. Furthermore, there are so many distinctive types of deposit peculiar to the Cobalt formation which are never found in the Bruce conglomerate that they can generally be distinguished on lithologic evidence alone.[4] The writer is convinced that the Ramsay Lake conglomerate of Falconbridge township is the representative of the Bruce conglomerate of the original Huronian area.

Collins[5] has identified the Ramsay Lake conglomerate of Ramsay lake as the equivalent of the quartzitic basal conglomerate of the Mississagi formation. The local name Ramsay Lake conglomerate, having served its purpose, may now, therefore, be abandoned.

Sudbury Series

Part of the formations correlated with the Bruce series in this report have previously been mapped and described by Coleman and Collins[6] as part of the Sudbury series, of pre-Huronian age. It is advisable, therefore, to explain the basis of this revision. It is only fair to begin by pointing out that the work of Coleman and Collins here referred to was done before Collins began in 1914 his exhaustive study of the original Huronian formation along the north shore of lake Huron. These studies have given us a knowledge of the true order of succession of the Precambrian formations, familiarity with the formations as geologic units, a recognition of the changing phases of certain formations, and, in certain cases, the means of diagnosing these phases by lithologic and minor structural criteria[7]. These means of correlation have been applied in any other areas since 1914 to the great simplification of geologic problems bearing upon the stratigraphy of the Sudbury and Lake Huron areas.

Although Coleman observed in 1905 that the granite at the Murray mine, near Sudbury, was intrusive in the norite, it was not generally recognized that any of the granites in northeastern Ontario intruded the Huronian sediments until the publication of Collins' bulletin on the age of the Killarney granite. Hence when sedi-

[1] Coleman, A. P., Idem, p. 9. Compte-Rendus, Congrès Géologique International, 12ième Session, Canada, 1914, p. 389.

[2] Collins, W. H., Congrès Géologique International, 12ième Session, Canada, 1914, Compte-Rendus, p. 404. Wanapitei Sheet, Map No. 124A, Geol. Surv., Can.

[3] Miller, W. G., and Knight, C. W., Jour. Geol., vol. XXIII, pp. 589 and 594, 1915.

[4] Jour. Geol., vol. XXIX, 1920. pp. 470-472.

[5] Collins, W. H., personal communication.

[6] Coleman, A. P., Ann. Rept., Ont. Bureau of Mines, vol. XXIII, pt. 1, pp. 213-214, 1914.
"Problems of American Geology," p. 97, 1915.
Collins, W. H., Geol. Surv., Can., Sum. Rept., 1913, pp. 190-191.

[7] Collins, W. H., Geol. Surv., Can., Mus. Bulls. Nos. 8 and 22.
Quirke, T. T., Jour. of Geol. vol. XXIX, 1920, pp. 470-471.

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mentary formations were found much folded and invaded by granite they were commonly referred to the pre-Huronian division. Coleman found at Sudbury a succession of arkose, greywacke, and quartzite, all highly folded and metamorphosed. These he included, under the names Copper Cliff arkose, McKim greywacke, and Wanapitei quartzite, in the Sudbury series, regarding them as of pre-Huronian age and separated from the Huronian (Cobalt series) by a great interval of mountain-building and peneplanation.

In the Lake Wanapitei area only the Wanapitei quartzite is present; but it is so associated with other formations of the Bruce series as to indicate it to be the Mississagi quartzite. The order of the formations mapped is the same as that in the Bruce series of the original Huronian area with the possible exception of the Espanola limestone, as follows:

Feldspathic impure quartzite (Serpent quartzite).
Stratified silty greywacke (Espanola greywacke).
Siliceous limestone (Bruce limestone)
Massive conglomerate (Bruce conglomerate).
Faint unconformity
Feldspathic quartzite, arkosic and conglomeratic at base (Mississagi quartzite or Wanapitei quartzite).

The character of these formations in the area and their succession identify them with the Bruce series. The identity of the Wanapitei quartzite with the Mississagi, has further been established by Collins, who in 1917,[1] traced the Mississagi quartzite continuously from Espanola to lake Wanapitei and found it to correspond to the Wanapitei quartzite of Coleman.

The McKim greywacke and Copper Cliff arkose formations of the Sudbury series do not occur in the Wanapitei map-area, but in Sudbury district Collins has found some evidence of unconformity between the Mississagi (or Wanapitei) quartzite and the McKim greywacke beneath it. The basal member of the Mississagi (or Wanapitei) quartzite is a thick bouldery conglomerate (the Ramsay Lake conglomerate, of Coleman) which carries a few pebbles of a sheared greywacke apparently derived from the McKim formation. The exact contact between this basal conglomerate and the McKim greywacke was found in only two places and does not throw much additional light upon the nature and importance of the unconformity.

ECONOMIC GEOLOGY

ORE DEPOSITS

Nickel and Copper

The deposits of nickeliferous pyrrhotite underlying the eastern end of the Sudbury norite which extends into the Wanapitei area have been so fully treated by Coleman that it would be wasted effort to discuss them further, except to mention that none of the properties within the map-area is now being worked.

Gold and Iron

In addition to the claims for nickel and copper, there are many claims for iron and gold. The iron ore deposits which lie in the northwestern corner of the map-area have been described by Miller[2] and need no further mention, except the repetition that they are probably of no value.

The prospects for gold deserve more extended consideration. Several claims have developed into mines, but none has been financially successful. In most cases the gold is there in specks, wires, or pieces of considerable size, but the deposits were

[1] Unpublished information about to appear upon a general geological map of northeastern Ontario, Geol. Surv., Can., No. 155A.
[2] Miller, W. G., Ont. Bureau of Mines. 1901, p. 177.

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too patchy or otherwise too limited to bear the expense of mining and milling. All the mines are now abandoned. However, prospecting continues with some expectation of the discovery of profitable gold deposits.

The best known mine is the Crystal mine, which lies between Bowland and Matagamisi lakes. The main shaft is sunk in the crest of a hill of greywacke; the mill timbers and the wreck of some machinery are at the base on the shore of lake Bowland. The ore-body is a quartz vein which lies between diabase on the east and greywacke (Gowganda formation) on the west. The vein minerals are quartz, pyrite, and a carbonate, probably breunnerite (carbonate of iron and magnesium) judging from its tan-coloured weathering. The gold is free milling. Collins[1] has reported that the gold ore deposits of this district differ from the usual type in northern Ontario, and he described the Crystal mine and the geological relations of its deposits.

In many other places on the east side of lake Wanapitei, at or near the contacts of diabase and partly in the Huronian rocks, there are quartz veins which carry visible gold. The gold is free, and much of it is wire gold, which suggests that it is derived from sulphides during weathering. The gold has not been found in the country rock, outside the veins, which makes it unlikely that disseminated deposits will be found at least in the more siliceous types of rock. The commonest association of vein minerals is quartz, pyrite, galena, and gold. In the Crystal mine, and in a prospect along a great fault line between lakes Wanapitei and Ashganing, the minerals are quartz, pyrite, carbonate, and gold.

A good deal of prospecting for gold has been done in the northwest part of the area in the Keewatin formation, where the banded iron formation occurs. A prevalent idea among many prospectors seems to urge them to prospect for gold wherever there are jaspilyte beds in the schists. They believe that the iron has a precipitating effect upon gold solutions. Authenticated instances of gold-bearing quartz veins being associated with so-called "banded iron formation" are, however, more easily explained as follows: the Keewatin schists are older than many igneous intrusions which might have been responsible for episode after episode of mineralization, and the Keewatin schists contain numerous streaks of siliceous iron deposits, known as jaspilyte; consequently some of the gold-bearing quartz veins in the Keewatin rocks happened to intersect the banded jaspilyte. It is very doubtful, however, if jaspilyte itself is a good indication of gold-bearing quartz veins.

A much better guide for the prospector in the Lake Wanapitei area is the contact of diabase and Huronian sediments. As Collins observed, the gold deposits are in every case closely connected with a diabase intrusion. To this it may be added that gold-bearing quartz veins have been found along the line of major faults near diabase intrusions, the faults being younger than the intrusions. These quartz veins, however, are patchy and their content of gold irregular.

In the further prospecting for gold all major fault lines passing close to diabase intrusions should be examined carefully, especially the fault slightly west of the mouth of Mountain creek; the fault between lakes Wanapitei and Ashganing; and the fault line with a northwest-southeast bearing about one mile east of the outlet dam on lake Wanapitei. Along this last fault is a remarkable replacement of Mississagi quartzite by large feldspar crystals, apparently adularia. Such a replacement is thought to indicate the intrusion of hot aqueous solutions. Limestone outcrops should also be followed to their contact with diabase; such places may be found west of Mountain creek, and in Scadding township, according to the map (No. 1948) which accompanies this report. In Scadding the soil is so thick that none of the limestone outcrops could be followed very far; however, certain contacts of limestone and diabase are mapped, and it is recommended that these should be explored thoroughly, in the search not only for mineral veins but for disseminated deposits of gold-bearing pyrite.

[1] Collins, W. H., Geol. Surv., Can., Mem. 95, 1917, pp. 114-115.

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RADIUM-BEARING PEGMATITES OF ONTARIO

By H. V. Ellsworth

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INTRODUCTION

Radium-bearing minerals were discovered near Parry Sound in February, 1921, and in August the writer was detailed to examine these prospects and to visit any other localities in Ontario where such minerals have been found or might possibly occur. As the radium-bearing minerals so far discovered in Ontario occur in pegmatite, the work resolved itself into an examination of pegmatites in general, particularly those which have been opened up for the mining of feldspar or white mica. Nearly all the feldspar or white mica mines in Ontario of which records were obtainable, besides numerous radium mineral prospects, were visited, but the time available for examination was in many cases brief. The main object of the investigation was to estimate the possibility of a commercial production of uranium-radium ore from these deposits; a secondary object was the collection of data that might prove useful to prospectors for radium minerals in other areas. Further, the analysis of uranium minerals provides a means of estimating the actual age in years of the rocks in which they occur; a point of much more practical importance than appears at first sight. There has been, and is, great divergence of opinion among Precambrian geologists as to the correlation of the widespread irruptive invasions known as the Laurentian, Algoman, Killarney, and other granites. The relationship of the Grenville-Hastings areas of Quebec and eastern Ontario to the Keewatin and Huronian of western Ontario has never been satisfactorily settled. If it were possible to obtain uranium minerals from these various granites their respective ages could be calculated, and correlation problems that have hitherto defied all other methods of attack could be solved. Apart, therefore, from the purely commercial possibilities of radium production the finding of uranium minerals may be of great practical importance in helping to solve some of the most difficult problems of Precambrian geology in Ontario and Quebec.

As a result of this investigation radioactive minerals have been found in small amounts in the majority of the workings visited, extending from Parry Sound eastward nearly to Kingston. It thus appears that uranium and thorium minerals are of quite common occurrence and widely distributed in the Precambrian rocks of this part of Ontario, though usually present only in very small quantities.

Before proceeding to the description of the various prospects, it may be worth while to say something about radium, its uses and the present situation with regard

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to its production. For the data included in this part the writer has drawn on the well-known publications of Rutherford, Boltwood, Ramsay, Soddy, the U.S. Bureau of Mines, and others. Those interested in the subject of radioactivity will find the scientific side extremely well presented in Rutherford's "Radioactive Substances and Their Radiations," and the practical aspects of radium production, occurrence of ores, etc., are equally well covered by the U.S. Bureau of Mines Bulletins 70, 103, and 104.

RADIUM AND ITS PROPERTIES

Radium is a white metal resembling barium in general chemical properties. The metal has been produced only in small quantities for experimental purposes. In commercial refining processes it is obtained in the form of a compound with chlorine or bromine, hence the term radium as popularly used refers to radium chloride or bromide. In this form when freshly prepared it resembles common table salt in appearance.

Radium by itself or in compounds, possesses the remarkable property of spontaneously changing into the gas helium and the metal lead. What is perhaps just as remarkable, it does so at a fixed rate which is entirely unaffected by any alteration in temperature and pressure which it has been possible to apply up to the present. This rate is such that half of the radium is changed in 1,690 years. In the next 1,690 years half of the remainder, or one-quarter of the original quantity disappears, and so on. The transformation is not a simple, direct process, however, but takes place in stages, a number of substances of decreasing atomic weight being formed, which are really short-lived chemical elements, each breaking down to form the next in succession until the final result is a quantity of lead and helium equal in combined weight to the radium which has decomposed.

One of these intermediate substances commonly called radium emanation is of great practical importance. It is a gas, the heaviest known, having according to Rutherford one hundred and eleven times the density of hydrogen. In the treatment of cancer in institutions where comparatively large quantities of radium are available the radium chloride is kept in solution and the emanation as it accumulates is boiled off and compressed into hollow needles or other devices convenient for application. In this way greater economy and safety in the use of radium is obtained than if the radium salt itself is used. The emanation loses its potency in a short time, having a half-life period of only 3·35 days.

The disintegration of radium is accompanied by the release of a relatively enormous amount of energy. Radium produces more than enough heat to melt its own weight of ice every hour, and three types of radiations are given off called the alpha, beta, and gamma rays. The alpha rays consist of atoms of helium carrying positive electricity and travelling at a rate of about 12,000 miles a second or about one-fifteenth the velocity of light. The beta rays are extremely minute negatively charged bodies having a velocity of from 100,000 to 186,000 miles a second, or about the velocity of light, and their mass is estimated at only one sixteen-hundredth of that of the hydrogen atom. They are thought to represent the smallest unit having a part in the constitution of matter. The gamma rays unlike the alpha and beta rays are imponderable, being ether vibrations of very short wave length, like X-rays. All these radiations will affect a photographic plate and will discharge an electroscope, though in different degrees. The alpha rays are most effective in discharging an electroscope but have very little power of penetration, being stopped by a thin sheet of paper. The beta rays have about one hundred times the penetrating power of the X-rays, and the gamma rays will penetrate a foot of iron.

A substance which gives off one or more of these types of radiations is said to be radioactive.

Radium itself is formed as a result of a similar spontaneous disintegration of uranium, which, however, takes place much more slowly than in the case of radium,

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the time required for the disappearance of one-half of any amount of uranium being about 5,000,000,000 years. In a ton of uranium element only about one-eighth of a milligram disintegrates annually. Thus geologically old uranium minerals furnish the only commercial source of radium, since a very long time is required for the accumulation of appreciable quantities.

A gram of uranium with its various distintegration products produces $1{\cdot}88 \times 10^{-11}$g. of helium and $1{\cdot}21 \times 10^{-10}$g. of lead per year. Hence if the percentages of uranium and of lead or helium in a mineral are known, the age of the mineral in years can be determined, assuming (1) that no lead or helium was originally present in the mineral at the time of its formation and (2) that the rate of transformation in the past has been the same as that observed at the present time. There is good evidence both experimental and geological to justify these assumptions, and geological age determinations according to this method are regarded as the most accurate and reliable that can possibly be obtained in our present state of knowledge. If we suppose a uranium mineral to be free of radium at the time of its formation, during millions of succeeding years radium is slowly produced and gradually accumulates, though it is at the same time changing to helium and lead. Eventually equilibrium between formation and decay is established; after a period estimated at from 1,000,000 to 10,000,000 years, all uranium minerals which have not suffered alteration should contain the equilibrium amount of radium corresponding to their uranium content. Numerous investigators have determined this constant with quite concordant results. The most recent determination of Lind and Roberts agrees exactly with an earlier one of Rutherford and Boltwood. This ratio is stated as follows:

1 gram of uranium is in radioactive equilibrium with $3{\cdot}4 \times 70^{-7}$ grams of radium.

In practical units 1 milligram of radium is contained in about 7·66 pounds of uranium oxide (U_3O_8) in unaltered old uranium minerals. Or if the ratio is placed at 1 milligram in 8 pounds of U_3O_8 we have a figure representing a safe working basis for commercial calculations. It follows from this relationship that the quantity of radium present in an unaltered ore can be calculated from the percentage of U_3O_8 as shown by chemical analysis.

Thorium is an element having radioactive properties similar to uranium, and like it changes into helium and lead through a series of intermediate substances. The disintegration of thorium is about three times slower than that of uranium. Thorium produces a highly active product, mesothorium, resembling radium in its properties and inseparable from it by chemical means. All thorium minerals contain some uranium and most uranium minerals carry some thorium. Hence all mesothorium preparations contain some radium and radium may contain mesothorium. The radium produced from United States carnotite, however, appears to be almost free from mesothorium.

USES

Popular interest in radium has been greatly stimulated in recent years by the increasing use of this rare element in the treatment of cancer and related malignant growths. As to the favourable influence of radium in cancer treatment there appears to be no longer any doubt. Institutions such as the General Memorial Hospital, New York, the Howard A. Kelly Hospital, Baltimore, and the New York State Cancer Hospital at Buffalo, which have had relatively large quantities of radium in use for a number of years report most favourably as to its beneficial action, though it is not effective in all cases. Its therapeutic use is being continually extended and includes many other diseases. It is worth noting that it is the very penetrating radiations or so-called gamma rays of radium or radium emanation, which are used in the treatment of cancer. The gamma rays are analogous to X-rays and it is not impossible that improvements in apparatus for production and control of X-rays may in future tend to lesson the demand for radium for this purpose. Radium has at present the advantage of much greater ease of application and control.

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Water containing radium or radium emanation is supposed to have valuable medicinal properties and is taken both internally and in the form of baths. The curative value of many of the famous mineral springs of Europe and particularly the spring at Bath, England, is now ascribed largely to the presence of dissolved radium or radium emanation. At Joachimsthal in Czecho-Slovakia, water from the pitchblende mines is utilized in this way. This is worthy of note, as highly active springs may be found in the neighbourhood of the radium-bearing mineral occurrences in Ontario and such springs would, if properly exploited, undoubtedly prove a strong additional attraction for tourists and visitors to that already famous vacation land, the "Highlands" of Ontario.

The other chief commercial use of radium is in the making of the familiar luminous paint used on watches, compasses, etc. Here radium has a competitor, mesothorium, a by-product of the thorium gas mantle industry, which is cheaper and serves well while it lasts, though its effective life is short—only five to six years. On the other hand genuine radium paint preserves its luminosity indefinitely.

Experiments have been made which indicate that radium increases the growth and yield of plants, so that tailings and residues from the treatment of radium ore may have some commercial value as a fertilizer because of the small amount of unrecovered radium they contain in addition to other elements present. A company has been formed recently in Czecho-Slovakia to exploit radioactive fertilizers. Should the pegmatites ever be worked for their radium content the tailings and residues if finely ground should also be of value for their potash content, which would slowly become avaliable when applied to the land. In considering the development of the Ontario deposits the necessity of providing a market for the tailings or residues cannot be over-emphasized, since the ores are in general too poor to be profitably worked for the uranium-radium content alone.

A new use for radium is developing in the gem industry where it is used for colouring, decolourizing, or otherwise altering or improving the colour of precious stones. Apparently, however, such changes are not always permanent.

PRODUCTION

The world's total production of radium up to January, 1921, has been estimated by the United States Bureau of Mines at approximately 155 grams, or about 5 ounces. Of this the United States has produced 115 grams, which was obtained entirely from the carnotite and kindred ores of Colorado and Utah. Of the 40 grams produced outside of the United States, at least 10 grams are thought to have been made from American ore. A certain amount of carnotite ore is exported and at one time pitchblende ore produced from old gold mines in Gilpin county, Colorado, was sold in Europe.

It is impossible to obtain reliable data as to the amount of carnotite ore still available in the United States, for little drilling or deep development work has been done, and the workings are largely superficial and pockety. Probably, however, the greater part of the high-grade ore has already been exhausted. Writing in 1918 R. B. Moore, of the United States Bureau of Mines, stated that "In my judgment the carnotite fields will not produce more than 100 additional grams of radium element at the most—if that much. This would about double the world's present supply, but on account of the large use of radium in cancer treatment such an amount though large scientifically, would be small in proportion to the probable demands." Since this was written about 80 grams have been produced in the United States as follows: 1919—11·8 grams; 1920—32·5 grams; 1921—35 grams estimated.

In Europe radium has been produced in relatively small quantities ever since its discovery from the pitchblende deposits of Joachimsthal and from various localities in Saxony. Autunite ore (uranium-calcium phosphate) carrying 0·3 to 1 per cent U_3O_8 has been exploited in Portugal.

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Two companies at least are mining for pitchblende in Cornwall and one is said to be producing very rich ore in commercial quantity. The pitchblende ore is associated in origin with the well-known tin deposits which have been worked since the time of the Phoenicians.

At Olary in South Australia a refractory low-grade ore containing much titanium and iron, with some rare earths, has been successfully worked.[1] The ore is concentrated, the concentrates comprising 30 per cent of the ore contain 1·6 per cent U_3O_8, so that the ore itself carries only 0·5 per cent U_3O_8. That there exists a commercially successful process for obtaining radium from an ore of this kind is of special interest as it appears that such lean and refractory minerals are on the whole of more common occurrence and more abundant in Ontario than the rich, easily refined uraninite. There is no record so far of a commercial production of radium based on uraninite from pegmatite.

The price of radium salts depends partly on the quantity purchased and partly on the purity of the product. On the whole, prices have been steadily rising since the beginning of commercial production. During 1921 the price in the United States was $115 to $120 a milligram of element for small lots. For larger quantities subject to competitive bids, prices were somewhat lower. The price may be stated as roughly from $3,000,000 to $3,500,000 an ounce. Radium is sold in the form of chloride or bromide, but the price is reckoned on the amount of element present as determined by electroscopic measurements of the gamma ray activity. Commercial preparations usually contain impurities, notably barium salts and possibly some mesothorium. The latter has properties similar to radium but decays in a few years. Mesothorium sells for $60 to $70 a milligram. A milligram is about $\frac{1}{31{,}000}$ ounce, Troy.

Owing to the scarcity of ores and the relatively high cost of mining and extraction it does not appear likely that the price of radium will decline, but rather otherwise.

GENERAL GEOLOGY OF THE RADIOACTIVE MINERAL OCCURRENCES IN ONTARIO

All discoveries of radioactive minerals in Ontario with the exception of a lost locality on lake Superior, have been in the area of Precambrian rocks south of French and Ottawa rivers and west of a line between Ottawa and Kingston. In this area there is an ancient highly metamorphosed sedimentary series consisting of crystalline limestones, quartzites, and paragneisses, which is intruded by a great variety of gneissic eruptives varying from granite to gabbros, anorthosites, nepheline rocks, etc. The sedimentary rocks have been called the Grenville and Hastings series and probably are equivalent in age to the great area of similar rocks which extends through Quebec to the Labrador coast. The limestones and paragneisses attain their greatest development in eastern Ontario. In the Parry Sound district the only crystalline limestone seen was in the neighbourhood of Seguin Falls. Particularly good exposures occur at Healey Falls on the road 6 miles north of Seguin Falls station, Grand Trunk railway. This is typical coarse crystalline limestone containing small crystals of pyroxene, phlogopite, and graphite, and appears to be exactly similar to the Grenville limestone in eastern Ontario and Quebec.

Throughout the area enormous quantities of pegmatite occur in dykes and intrusions of all shapes and sizes, from a few inches to 100 feet or more in width and 1,000 feet or more in length. The majority of the pegmatites are of the granite type in composition, consisting chiefly of potash and potash-soda feldspar and quartz with accessory minerals such as muscovite, biotite, hornblende, garnet, and various other minerals. Syenite pegmatites occasionally occur as at Craigmont and north of

[1] "Extraction of Radium from Olary Ores," by S. Radcliffe, Jour. Roy. Soc. of N.S. Wales, vol. 47, 1913.

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Kingston. In general, three types may be distinguished, though where large exposures are available these structures are often seen to grade into one another.

(1) Segregated type: feldspar in solid crystalline masses often several feet in diameter with the quartz also in large pure masses and often moulded on large crystal faces of the feldspar.
(2) Graphic type: graphic intergrowth of quartz and feldspar. This intergrowth may be fine or coarse.
(3) Granitoid type: in which the feldspar and quartz occur as individual grains though often of large size. This appears to be simply very coarsely crystallized granite.

The above classification has been adopted as furnishing convenient designations applicable without qualification to most of the pegmatite exposures met with in the area examined. All these types of structure may sometimes be seen in one dyke, however, particularly if it be large and well exposed.

The largest dykes encountered, often from 50 to 200 feet wide and 1,000 feet or more in length, are as a rule of the graphic type and sometimes contain almost no minerals except quartz and feldspar. At other times much scaly white or black mica is present.

The smallest dykes, from a few inches to a few feet in width, are most often of the granitoid type. The segregated type occupies an intermediate position as to size. An example of the segregated type is shown on Plate II. The highest grade of crystal pottery spar is produced from dykes of the segregated type.

From observations so far made it appears that uraninite is most likely to be found in dykes of the segregated type, whereas complex minerals such as those of the euxenite group, niobates, tantalates, and titanates generally, and allanite, seem to be most at home in the graphic or granitoid type of pegmatite.

ECONOMIC MINERALS OF THE DYKES

FELDSPAR

The pegmatite dykes of Ontario and Quebec constiture probably the greatest reserve in the world of high-grade potash feldspar. The mining of feldspar has been for years a modest but growing industry and although the depression of the last two years coupled with excessive freight rates has for the time being reduced the output, it is none the less likely to become an important and stable industry. A reduction in railway and ocean freight rates would open up a very large market in England and the Continent. At present almost all our feldspar goes to the United States in the rough state and is ground there. Ground Canadian spar is even shipped back into Canada. In many cases there are small but sufficiently powerful and easily developed waterfalls near enough to deposits to permit of grinding the feldspar at very low cost. Feldspar as mined sells for $6 to $9 a ton on cars.

MICA

The radium-bearing pegmatites contain muscovite and biotite but not phlogopite (amber mica), which is the main source of the mica industry of Ontario and Quebec. White mica or muscovite has been mined for many years from the pegmatites of the area. The mica is usually somewhat dark coloured and sometimes shows black spots. These, however, are said not to affect its use in the electrical industry, which takes most of the production. Trimmed mica brings 50 cents to $10 a pound depending on size of sheets and quality. Black mica has within the last year become saleable and inquiries for considerable quantities have been received from the United States. The price offered is somewhat lower than that of scrap mica.

The white massive quartz of the segregated type of pegmatite has occasionally been sold, but it is worth only about $2 or $3 a ton and does not pay to ship. In many cases this type of quartz is of remarkable purity and should be suitable for fused silica ware, optical glass, or wherever an extremely pure silica is required.

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RADIOACTIVE MINERALS

These minerals contain uranium or thorium or both and are mostly black or brown and rather heavy. If present in sufficient quantity they would constitute a valuable product. The most important ones found in Ontario deposits are:

Uraninite: Contains 70 to 80 per cent uranium oxide besides thorium, lead, and rare earths.

Euxenite-polycrase: May contain up to 10 or 15 per cent of uranium oxide with large amounts of titanium, tantalum, columbium, and rare earths. A little thorium is usually present.

Various other complex minerals occur. The mineralogy of the pegmatites has not yet been worked out in detail, but is in progress. Allanite, a silicate of aluminium, iron, and the rare earths, occurs in many of the dykes and in some cases shows considerable radioactivity, which is probably due chiefly to the presence of thorium.

It may be well to mention here the difference between uraninite and pitchblende. The latter term has been popularly applied to the mineral found in the Ontario pegmatites, but is not strictly correct. Pitchblende is a form of uranium oxide which is never found crystallized and which rarely, if ever, carries appreciable quantities of thorium and the rare earths. It occurs in metalliferous deposits such as those of Joachimsthal, Saxony, and Colorado. Uraninite, on the other hand, occurs as well-formed crystals of the cubic system, contains important amounts of thorium and the rare earths, and is found in granite pegmatite. Thus, though both minerals are essentially uranium oxide they are distinct in geological occurrence, composition, and to a certain extent, in physical properties.

If the rare minerals were to be separated from the feldspar and quartz by jigs or tables in all cases the resulting concentrates would contain several minerals, some of which would probably require a bisulfate fusion method of treatment such as used in the case of the Olary ores for extracting the radium or mesothorium. It would be impossible to produce pure radium from these minerals, as owing to the presence of thorium in the uraninite and other minerals the refined product would contain a certain amount of mesothorium. This, however, would not be objectionable for most uses.

Uranium, thorium, tantalum, columbium, titanium, and rare earth compounds could be obtained in some cases from such concentrates, often constituting valuable by-products.

It is impossible to say what price such a concentrate would bring, as there is none in the market, but some idea of the probable price may be obtained from the following quotation:

Carnotite ore,[1] per pound of U_3O_8—$1.25 to $1.75.

According to this quotation carnotite ore carrying 1 per cent U_3O_8 would be worth $25 to $35 per ton of 2,000 pounds. A concentrate carrying a higher percentage of U_3O_8 would be worth relatively more per pound of U_3O_8 than an ore carrying only 0·5 to 2 per cent. A rich uraninite concentrate carrying 25 to 50 per cent U_3O_8 should bring say $5 per pound of contained U_3O_8 as the refining costs on such a material would be much reduced.

INDICATIONS USEFUL IN SEARCHING FOR RADIOACTIVE MINERALS IN PEGMATITES

Radioactive minerals themselves are rarely if ever seen on weathered surfaces and can only be found by opening up the rock. The deep red colour shown by feldspar in the neighbourhood of such minerals, is, however, an almost infallible guide, which once seen is little likely to be mistaken for somewhat similar colours due to oxidation products of iron or manganese. Radioactive minerals do not attract a compass needle

[1] Chem. and Met. Eng., March 8, 1922.

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and can thus be distinguished from magnetite or ilmenite, with which they might otherwise be confused in the field.

Another very characteristic indication is the presence of small cracks or fractures in the rock radiating from the mineral in all directions. These radiating fractures occur in feldspar, quartz, or mica surrounding radioactive minerals and are apparently caused by pressure which the mineral has exerted outwardly, due possibly to increase of volume resulting from internal radioactive changes. Such cracks are best seen in quartz. In mica they may take the form of six-rayed pressure figures. Finally, a small amount of pale yellow "bloom" or decomposition product may sometimes occur in the neighbourhood of the minerals, on fractures, etc.

The electroscope furnishes the most convenient test for radioactive minerals. It is unnecessary, however, for prospectors to purchase an instrument, since the services of the Provincial and Federal Mines Departments are always at their disposal. An ounce or less of material is sufficient for the test.

PARRY SOUND OCCURRENCES

Uraninite was discovered near Parry Sound, Ontario, in February, 1921, by James Robinson. The claims are now jointly held by H. F. McQuire and the Robinson brothers, all of Parry Sound. Other claims have since been located.

The McQuire-Robinson claims are included in the block comprised by lots 6 to 10, concessions IX and X, Conger township, Parry Sound district. This block lies between Blackstone lake and the Toronto-Sudbury line of the Canadian Pacific railway. The claims may be reached by a trail from Brignall flag station on the above line (12·8 miles southeast of Parry Sound) or by an old, partly overgrown settlers' road which starts in concession IX from the main road on the township line between Conger and Humphrey, and runs westward to Blackstone lake. None of the claims is more than a mile in a direct line from the railway (Figure 4).

The area is rocky, with numerous low hummocks or hills mostly less than 100 feet high. It is covered with thick small growth and some scattered hardwood. The drainage is towards Blackstone lake. The elevation is from 800 to 900 feet. There are no farms or clearings in the block.

The rocks are ancient Precambrian crystalline schists and gneissic eruptives probably of the same age as those of the Hastings-Grenville areas to the east. The larger hills are often mainly granite, whereas hornblende schists predominate in the valleys or lower ground. Masses of basic eruptive rock such as gabbro or norite also occur. Granite-pegmatite is abundant, forming dykes which are seen most often intruding the hornblende schists. The pegmatite dykes are found more often around the edges of the granite masses than in the masses themselves. Uraninite has been found only in the pegmatites, which represent the final products formed on the cooling of the granite masses.

It should be noted that this occurrence of radium-bearing minerals, as well as all others in Ontario, is of an entirely different type, both geologically and mineralogically, from the carnotite deposits now being worked in Colorado. The Colorado ore is a friable sandstone, a sedimentary rock, of Jurassic age, very much younger than the Ontario pegmatites, which has been more or less impregnated with the uranium-bearing mineral carnotite. Pure carnotite is a powdery yellow substance containing up to 55 per cent uranium oxide besides vanadium and other elements. The carnotite ore as mined runs from 1 per cent to 3 per cent uranium oxide according to some writers, but as it has been stated that 500 tons or more of the ore is required to produce one gram of radium, it would follow that the average tenor of the ore is probably somewhat less than 1 per cent uranium oxide.

In the case of the Conger Township occurrences the mother rock is of a very much older geological period, and has been produced by the cooling of masses of molten

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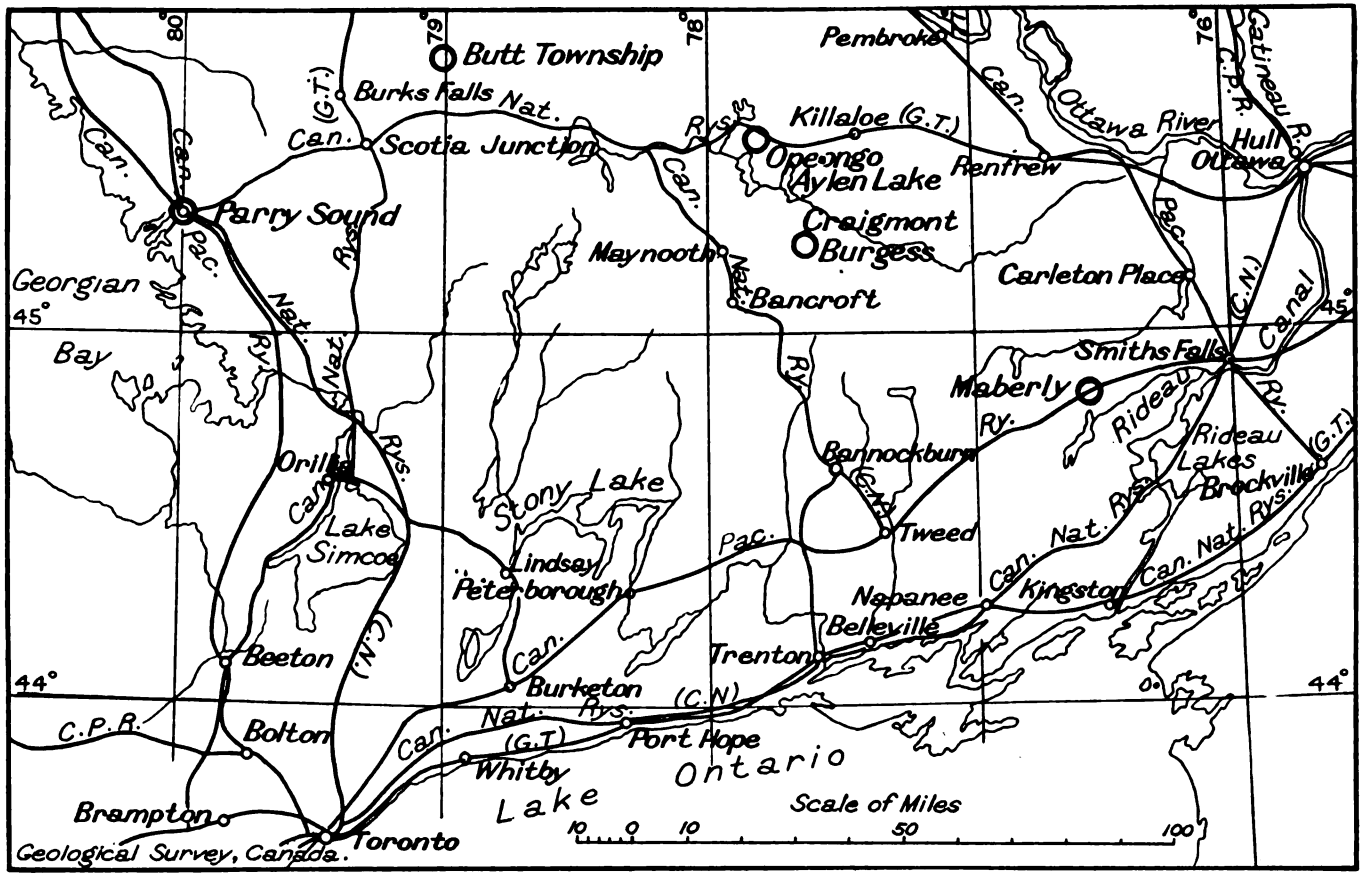

Figure 4. Index map showing locations of the principal known occurrences (in circles) of radioactive minerals in Ontario.

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granite. The radium-bearing mineral is uraninite carrying up to 80 per cent uranium oxide. It is, therefore, richer in radium than the carnotite, since the radium content is proportional to the uranium present.

The granite of the area is noteworthy for the presence of numerous small manganese garnets, similar to those which occur in larger sizes in many of the pegmatite dykes. The granite is somewhat gneissoid, but, on the whole, is remarkably uniform in texture, and of a rather pleasing pinkish colour which is due partly to the oxidation of the garnets. It should make a good building stone, as very large blocks of uniform texture and colour could be obtained in certain localities. An analysis of a large composite sample from three different ridges yielded results as below:

	Per cent		Per cent
SiO_2	74·22	Na_2O	3·38
Al_2O_3	12·79	P_2O_5	0·01
Fe_2O_3	1·17	S	0·01
FeO	0·97	$H_2O+110°$ C.	0·33
MnO	0·11	$H_2O-110°$ C.	0·18
TiO_2	0·19	Ba, Sr, Zr, F	not detected
CaO	1·22		
MgO	0·38		
K_2O	4·99		99·95

The garnet granite is thus a typical granite with no special component except spessartite garnets. The connexion of the uraninite-bearing pegmatites of the district with this particular granite is well established by the occurrence of the same garnets in larger sizes in the pegmatites themselves. Strangely enough, there appear to be almost no garnet paragneisses in the immediate neighbourhood.

Minerals of the Dykes. The pegmatitic dykes consist chiefly of pink to red potash feldspar with from 25 per cent to 50 per cent of quartz. The quartz is of two varieties: (1) white and massive—usually very pure; (2) smoky and granular and mixed with feldspar, mica, etc. Both biotite (black) and muscovite (light) mica are found in large books in certain of the dykes. Uraninite occurs as isometric crystals or rounded grains, varying from ½ inch to 1 inch, but mostly ¼ inch or less in diameter. The usual crystal form is a combination of the cube and octahedron. It is found most often and most abundantly in intimate association with small white mica in a granular mixture of deep red feldspar and smoky quartz. It occurs less commonly alone in the feldspar and rarely in the massive white quartz of the pegmatites. The feldspar around the uraninite crystals is a deep red, noticeably darker than where uraninite is absent. This coloration of the feldspar is very characteristic, and important as an indication of the presence of radioactive minerals.

Red garnets of the manganese variety, spessartite, occur in some of the dykes, and a brownish, altered mineral in long crystals, sometimes several inches long, which qualitative tests indicated to be allanite. The allanite is somewhat radioactive and probably carries some thorium and uranium. One or more other rare minerals are also present, but the uraninite is the one of chief commercial interest. From several ounces of uraninite presented by Mr. McQuire, a representative sample for analysis was prepared by selecting apparently unaltered pieces from about thirty crystals or 'nuggets'. The uranium figures for such a sample will, of course, be higher than the general average, which should include the more or less altered uraninite. As, however, it was desirable to obtain results which could be used for determining the uranium-lead ratio, only the best pieces were selected. The analysis, which was conducted in duplicate with every precaution, yielded results as below:

	Per cent
Uranous oxide—UO_2	53·63
Uranic oxide—UO_3	26·32
Lead oxide—PbO	11·67
Thorium oxide—ThO_2	3·22
Yttrium group oxides	2·19
Cerium group oxides	0·98

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	Per cent
Calcium oxide—CaO	0·41
Iron oxide—Fe_2O_3 / Aluminum oxide—Al_2O_3	0·17
Manganese oxide—MnO	present, less than 0·01
Silica—SiO_2	0·29
Water—H_2O	0·72
Insoluble	0·13
Magnesium oxide / Zirconium oxide / Bismuth oxide / Potassium oxide / Sodium oxide	Doubtful traces
	99·74

Specific gravity 9·116 at 17·43° C.

The helium has not yet been accurately determined, but it is present in large amount. The total uranium element present is 69·19 per cent and lead 10·83 per cent. Using the latest data very kindly supplied the writer by Sir Ernest Rutherford the age of the uraninite works out as follows: $\frac{Pb}{(U + 0.38\ Th)} = 1.21 \times 10^{-10} \times t$ where t= the time in years. Inserting the figures for lead, uranium, and thorium we obtain: $0.154 = 1.21 \times 10^{-10} \times t$ or t= 1,272,000,000 years. The age of the granite is thus indicated to be 1,272,000,000 years and the series of rocks intruded by the granite is, of course, still older.

An interesting feature is the occurrence of a material resembling anthraxolite in association with the uraninite. This is a lustrous black substance consisting chiefly of fixed carbon, which burns apparently without giving off any volatile hydrocarbon and leaves a small amount of blackish residue. The residue is rich in uranium. The occurrence of this carbonaceous material may have an important bearing on the origin of uraninite.

Feldspar of excellent pottery grade occurs in several of the dykes and the graphic type of material consisting of an intergrowth of quartz and feldspar occurs in very large bodies hundreds of feet in length.

Large sheets of white mica could be obtained from certain of the dykes and would be a valuable product. The mica is of excellent quality except for the rather common occurrence of black spots, which, however, probably would not be objectionable for many electrical uses. In most cases these black spots seem to be minute and extremely thin included crystals of black mica, which probably do not appreciably affect the insulating qualities of the muscovite. Perfectly clear large sheets have been obtained, however, and these would sell for high prices. Black mica occurs in several of the dykes and is now saleable at about the price of scrap mica.

The best showing of uraninite is in the dyke on the line between lots 9 and 10, concession IX, near a bay of Blackstone lake (Plate I). The dyke is exposed on the side of a hill for a length of 70 feet. Its width over the rounded side is 50 to 60 feet, but the true width is not ascertainable as the dip or inclination is not known. It rises to a vertical height of perhaps 40 feet above a swampy creek gully. Nearly one-half of the exposed surface consists of massive white quartz, with a small amount of pink spar. The other half consists of mixed, smoky quartz, pink to red feldspar, and small white and black mica. Uraninite occurs as scattered grains chiefly in this area at or near the contact of this area with the massive quartz, particularly in association with stringers of small mica books. In August, 1921, several shots had been put in over the face and one pocket included within an area 2 feet square showed very abundant grains and crystals of uraninite from $\frac{1}{8}$ to $\frac{1}{4}$ inch diameter set in irregularly packed small white mica. This area would certainly make very rich ore and if such pockets could be found with sufficient frequency they would serve to enrich much of the poorer rock.

Large sheets of white mica have been taken from this dyke and probably more might be obtained.

Six other dykes have been to some extent opened up and show scattered small grains of radioactive mineral, probably uraninite. Some of these dykes carry a very good grade of feldspar, and might be worth working for spar, bearing in mind the chance of striking rich pockets of uraninite.

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It is difficult to estimate in the absence of large-scale sampling how much ore of commercial grade could be produced, but a rough idea may be obtained by determining what area of uraninite must be visible on exposed faces of the rock, in order to give ore of any determined percentage.

Taking the average specific gravity of the rock as 2·6 and of the uraninite as 8·86 and the average U_3O_8 content of the uraninite as 80 per cent we arrive at the result that in order to have say 0·5 per cent U_3O_8 ore, each cubic foot of rock must contain on the average 1 pound or 3·1 cubic inches of uraninite. If then the uraninite were uniformly distributed throughout a cubic foot of rock cut into forty-eight imaginary slices each ¼ inch thick and 1 foot square each slice would contain on an average, 8 cubes of uraninite each ½ inch on the side. We thus obtain some idea as to the amount of uraninite that should be visible on rock faces for any grade of ore. Similar rough calculations may be applied for euxenite and other minerals.

Other claims examined are those of Dr. Milton Armstrong, Parry Sound, on lot 6, concession X, Conger township; C. C. Calverly of Parry Sound, lot 5, concession VII, Conger township, and the farm of Moses Smith, south of Parry Sound. Little work had been done on these, but some scattered grains of radioactive minerals were visible.

Seguin Falls. Two days were spent in the neighbourhood, and dykes containing allanite discovered by D. Hall and A. MacKinnon were examined. As no mines were in operation only a short time was spent in the locality.

BUTT TOWNSHIP OCCURRENCES

Butt township, Nipissing district, is reached by a road from Kearney, on the Grand Trunk railway, 6 miles east of Scotia junction. The area is just west of the western boundary of Algonquin park. The road can be traversed by automobile as far as the Fish shacks on Maganatawan river (lot 28, concession VI, Proudfoot). From there a winter log road leads to what is called No. 2 camp, an old logging camp on lot 1, concession VI, Butt township. From No. 2 camp trails have been made to the various claims. Although the claims are by the existing road 20 to 25 miles from the railway, it is believed that a short cut nearly due south is practicable and would reduce the distance to 6 or 8 miles.

The country is rough and hilly. The elevation of the highest hills in Butt is about 1,600 feet above sea-level, and the hills may be as much as 300 feet above the valleys. There is a heavy covering of yellowish glacial sand, so that rock exposures are rarely seen except on the steep sides of hills. The forest consists of heavy second growth with considerable good hardwood, particularly birch, in places. The sand and second growth make prospecting difficult, and the claims even as so far developed represent a great deal of hard work.

Essentially the same series of rocks occur as at Parry Sound, as far as can be judged from the few exposures. Garnetiferous granite like that at Parry Sound was observed at several places. Biotite and hornblende gneisses, often garnetiferous, are common and one or two small exposures of quartzite were seen. The general trend of the rocks is northeast-southwest. A majority of the pegmatite dykes strike from 20 degrees to 90 degrees east of magnetic north and often dip to the northwest. Dykes of the segregated type are common and sometimes are remarkably regular and veinlike in outcrops (Plate II), though when such dykes can be seen in any degree of completeness in two dimensions they prove to be really lens-shaped. The dykes are largest and best developed when they intrude mica or hornblende gneisses. Those which occur in granitic gneisses are mostly small, often not more than a foot wide. Basic irruptives, sometimes giving rise to small deposits of pyrite and pyrrhotite, occur. A few miles east of Burks Falls a shaft was sunk and nickeliferous pyrrhotite was mined about twenty years ago. No crystalline limestone or indications of its presence were seen in this area.

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Wm. Elliott Claim. The first uraninite discovered in Ontario came from the mica mine of Wm. Elliott, situated on the south half of lot 13, concession VII, Butt township. The occurrence has been well described by C. W. Knight of the Ontario Bureau of Mines[1] and there is nothing to add to his description. At the time of the present writer's visit the dyke was exposed for a length of 90 feet and is probably about 10 feet wide. The strike is north 30 degrees east magnetic and the dip is uncertain. The dyke is a granite pegmatite of the segregated type carrying a considerable quantity of white mica. Masses of white quartz and pink feldspar occur up to 3 feet in diameter. The spar mostly carries white mica. In addition there are areas of a granular mixture of deep red spar, smoky quartz, and small books of white mica just as in the uraninite dykes at Parry Sound. In this mixture small brownish allanite (?) crystals are fairly common and scattered grains of uraninite up to ¼ inch in diameter were seen. Some of these were collected. The uraninite sometimes occurs also in the more massive feldspar. Books of dark-coloured muscovite up to 5 and 6 inches diameter occur plentifully in the feldspathic areas. The mine was originally opened and worked for mica.

Bullock Claim. North half lot 11, concession VI, Butt township, owned by Mr. Bullock, of Chicago.

The dyke was opened for mica, and some good large books are said to have been obtained. The opening is a cut about 12 feet in diameter and 12 feet deep at the back, in pegmatite on the side of a hill. The dyke consists almost wholly of large solid masses of white quartz and pink potash spar with perhaps 10 per cent of the mixture of granular smoky quartz, red feldspar, and white mica. Red manganese garnets up to an inch in diameter, and ilmenite, are common. The garnets are particularly abundant in the granular mixture, but may occasionally be seen in both the massive white quartz and spar areas. There is little or no evidence of the presence of radioactive minerals. On the hill north of the cut there are some small rock exposures of the garnet-granite type. Other openings on the Bullock claims are not promising for radioactive minerals.

Mining Corporation Claims. North half of lot 14, concession VII, and south half of lot 14, concession VIII, Butt.

Shortly after the discovery of uraninite on the Elliott claim, the Mining Corporation of Cobalt became interested in the district, took up several claims, and did considerable trenching apparently in the hope of finding a narrow vein in which the uranium values might be more concentrated, as in some of the Colorado pitchblende veins. They uncovered a pegmatite vein about 350 feet long varying in width from 2 inches to a foot, and averaging 8 inches, which is remarkable for its regularity in length and width. Though vein-like in form it has a typical pegmatite filling consisting of feldspar and smoky quartz in about equal amounts with a little scaly black and white mica, and rather abundant garnets and ilmenite. No openings were made in the vein, but it was stripped along almost its full length. There are in places some slight indications of the presence of radioactive minerals in the way of red coloration, but none were actually seen. Coming up the hill from the west large exposures of typical garnet-granite are seen not far from this vein.

A. E. Trafford, Sundridge, Ont., Claim. South half lot 11, concession VII, Butt.

The dyke is 8 to 10 feet wide and 70 feet long striking north 15 degrees east magnetic. Openings show medium to coarse-grained spar and quartz with much black mica. No smoky quartz is present. Some small brown crystals, probably allanite, and some indications of radioactive minerals were seen.

A. E. Trafford Claim. North half lot 10, concession VII, Butt.

This is a dyke 18 inches to 2 feet thick lying on coarse foliated hornblende gneiss on the side of a hill, dipping at about 45 degrees to the northwest under drift, and

[1] Knight, C. W., Can. Min. Jour., Oct. 14, 1919.

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exposed by stripping for 40 to 50 feet up the hill. The exposed surface is really the wall of the dyke smoothly glaciated. The pegmatite is a mixture of medium-grain pink to red feldspar and quartz with white and black mica in books up to 3 or 4 inches diameter. There is some of the granular smoky quartz, deep red spar, and small mica mixture. Some scattered grains of radioactive mineral up to ¼ inch diameter were seen.

Frank Watson, Kearney, Claim. North half lot 10, concession VI, Butt.

A small stripping shows dykes 12 to 24 inches wide of pink spar, quartz, and small black mica. Some small brown crystals, probably allanite, were seen.

F. H. Armstrong, Kearney, Claim. South half lot 8, concession IX, Butt.

A stripping shows pegmatite 3 to 4 feet wide and 40 feet long striking due east and west, magnetic. The dyke is of the segregated type with 1 foot to 18 inches of massive white quartz in the middle and pink potash spar at the sides. Books of altered chloritic biotite up to 2 inches diameter occur in the spar. Magnetite or ilmenite and a few small brownish crystals up to an inch long, probably allanite, occur. No white mica or garnets, and only a little smoky quartz, were seen.

C. W. Beaton, Kearney, Claim. South half lot 7, concession IX, Butt.

A stripping shows a dyke 1 to 2 feet wide, exposed for 15 feet, striking east and west magnetic. A pit 8 feet long, 4 feet wide, and 8 feet deep has been sunk exposing light to pink spar with about one-third quartz and a little altered biotite. Ilmenite, a few small crystals, probably of allanite, and a little titanite were seen. No white mica, little or no smoky quartz, and but little deep red spar were seen.

R. G. Armstrong, Kearney, Claim. South half lot 7, concession X, Butt.

A stripping on the west side of a hill shows three pegmatite dykes from 1 to 3 feet wide converging at the bottom and exposed for 20 to 50 feet up the hillside. The pegmatite consists of pink potash spar and white quartz with a little black mica. Some small black crystals of a pitchy lustre surrounded by dark red spar were seen.

Napoleon Dault Claim. North half of lot 4, concession VI, Butt.

This interesting lens-shaped dyke, shown on Figure 5, exhibits on a small scale what appears to be the characteristic form of the dykes in this district if complete sections were available. It strikes due north and south magnetic, is about 6 feet wide at the thickest part in the middle, and tapers rapidly to nothing at both ends, the total length being 100 feet. There is a lens of white massive quartz 18 inches

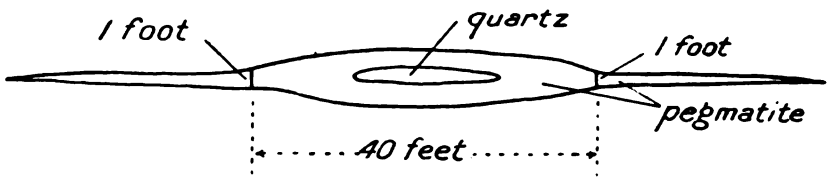

Figure 5. Diagram showing dyke on claim of Napoleon Dault.

wide in the middle of the widest part. The pegmatite is largely fairly coarse pink potash spar with some soda lime spar. Some smoky quartz and a little black mica up to 3 inches diameter occur and masses of magnetite or ilmenite up to 3 or 4 inches in diameter may be seen in the thickest part. Red garnets are abundant in places. Some brownish crystals, probably allanite, up to 1 inch long, were seen, and in some parts a little deep red feldspar.

John Ryan, Kearney, Claim. South half lot 6, concession VI, Butt.

A stripping shows a dyke 3 feet wide dipping 40 degrees to the northeast, consisting of about 80 per cent pink potash spar mixed with white and smoky quartz. Scattered grains of radioactive mineral occur. Another dyke on the same claim is 1 foot to 18 inches wide and the wall is exposed by stripping as a flat surface about

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30 feet up the hillside. It consists of about 80 per cent deep red spar with some smoky quartz and a little scaly black and white mica. Nuggets of radioactive mineral up to ½ inch diameter were quite abundant in one place where it had been opened up.

Claim lot 7, concession VI. A dyke 4 to 10 feet wide on this claim consists chiefly of pink spar with some white and smoky quartz and black mica. There is some evidence of the presence of radioactive minerals in the deep red spar and Mr. Ryan states that some grains of radioactive minerals have been found here.

W. H. Ryan, R. A. Mann, and D. J. Sheehan of Kearney, Claims. Lots 1, 2, 3, concession VI, Butt.

Traversing these claims in a nearly east and west direction is a large dyke which is better exposed and more opened up than any others examined in the district and will, therefore, be described in more detail. Its western extremity may be seen in vertical section exposed on an almost perpendicular hillside 40 or 50 feet high on lot 1. It here dips at 35 degrees to the north and cuts through foliated micaceous gneiss which strikes about due north and south. The dyke is 2 feet wide at the bottom of the hill, the width gradually increasing toward the top where it is 8 feet wide. It consists there of a coarse granular mixture of about 75 per cent reddish potash spar and quartz. A small amount of black mica in books up to 3 inches across, and a little smoky quartz, are present. No radioactive minerals other than small brownish allanite crystals were seen here. Three hundred feet east of this outcrop a stripping 40 feet long shows the dyke to be 6 feet wide and much coarser in texture. It contains masses of white quartz 2 or 3 feet in diameter which have a tendency to occur in the middle of the dyke with the spar similarly segregated at the sides. Black mica and some brownish allanite crystals occur here also and the owners state that a few grains of other radioactive minerals were obtained. Four hundred feet farther east (lot 2) on top of the hill—which rises 300 feet above the valley—another stripping exposes the dyke for 80 feet. It is here 6 to 7 feet wide and the quartz and spar are almost completely segregated. Masses of white quartz up to 2 feet wide fringed with patches of smoky quartz occupy the middle of the dyke with large crystals of spar which occasionally extend from side to side. The spar contains a little intergrown quartz and some black mica. A pit 15 feet long and 10 feet deep at the eastern end of the stripping shows that the dip is still 35 degrees to the north. Allanite and other radioactive minerals occur; the allanite chiefly at the edge of the dyke next the country rock, and other minerals at the contact of the smoky quartz and spar in the middle of the dyke. Two hundred feet east of this last outcrop, and still far up the hill, the dyke is again exposed for 50 feet. It is here about 10 feet wide. A pit 10 feet diameter and 15 feet deep has been sunk at the east end of the stripping. Segregation of the spar and quartz is almost complete, the quartz occurring in the middle in solid pure white masses, the spar on both sides and sometimes extending completely across the dyke and cutting off the quartz masses. The quartz is often moulded on large crystal faces of spar a foot or more across. Radioactive minerals are more abundant here than at any of the outcrops previously noted and the brown, waxy allanite crystals here attain their greatest size. They are as much as 1½ inches wide and 8 to 10 inches long and occur as usual in the spar next the walls. Smoky quartz, black mica up to 3 inches diameter, pyrite, a little chalcopyrite, and a few garnets occur.

About 17 or 18 chains east of this outcrop the dyke is again exposed by stripping for about 100 feet. This is on lot 3. The dyke here has a very uniform width of about 15 feet and is remarkable for its regular vein-like structure. The pure white quartz occurs as an uninterrupted band 5 to 7 feet wide in the middle with the spar equally developed on both sides (Plate II).

A pit 10 feet square and 15 feet deep shows that the dyke still dips to the north and becomes narrower as it goes down. Nuggets of radioactive minerals up to an inch in diameter, seen in the walls of the pit, are mostly associated with small white

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mica in the spar, but also occur in solid spar and in solid quartz. Small garnets, pyrite, and chalcopyrite are sparingly found. The radioactive minerals probably are chiefly of the complex type. They are at present under investigation. East of this exposure the dyke disappears into low ground and has not been traced farther east.

This very interesting dyke is evidently a portion of a lens-shaped body duplicating on a larger scale features shown by the small dyke on the claim of Napoleon Dault, previously described. Allanite (showing alpha-ray activity equivalent to as much as 3 per cent U_3O_8, but probably due mostly to thorium) occurs throughout the length of the dyke, but the richer minerals are almost confined to the highly segregated central portion.

An interesting feature not previously mentioned in connexion with this dyke is the evidence of plastic movement of the dyke body in a direction from west to east. This is shown by drag structures on the walls of partly assimilated country rock.

Mr. W. H. Ryan showed to the writer certificates of assays by John H. Banks and Son, 26 John St., New York, on three grab samples of the deep red feldspar as mined from the dyke on lots 2 and 3. Results: No. 1, 0·26 per cent; No. 2, 0·37 per cent; No. 3, 0·45 per cent of uranium oxide, U_3O_8. No. 3 sample was said to be across 3 feet of the spar on lot 3. A report by the same chemists, on concentration tests on another sample, is reproduced, in its essentials, below:

"Ore as received assayed 0·18 per cent U_3O_8.

Sample was crushed to pass 10 mesh and divided as follows:

Through 10 on 16 mesh
" 16 " 30
" 30 " 40
" 40 " 60
" 60 ..

Each of the above sizes was concentrated separately on a Wilfley table with the following results:

Ore		Concentrates		Tails
Mesh	Weight	Weight	Assay U_3O_8	Weight
−10 + 16	3,562 g.	51 g.	0·99%	3,511
−16 + 30	2,230	929		2,138
−30 + 40	685	12		673
−40 + 60	1,730	27	2·36%	1,703
−60	1,140	7		1,133
Totals.....	9,347	189	1·32%	

Weight of U_3O_8 in ore treated.. .. .. 16·82g.
Weight of U_3O_8 in concentrated.. .. .. 2·50%
Recovery U_3O_8.. .. .. 14·8 %"

It seems improbable that the recovery was actually as poor as indicated by these figures in view of the results obtained by the Ore Testing Division, Mines Branch, in concentration tests on the Maberley euxenite (page 68). The accurate determination of uranium in an ore of this nature by chemical methods is extremely difficult and on such low-grade material the analytical errors are relatively large and might easily account, partly at least, for the apparently very poor recovery.

The occurrences described are typical of the Butt district. A considerable number of dykes examined need not be mentioned here as they are not particularly noteworthy, though in many cases a few small scattered grains of radioactive minerals have been found. The exact analysis of the Butt Township uraninite has not yet been completed, but preliminary results indicate that it is of the same composition and age as the Parry Sound material, containing about 10 per cent of lead.

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OPEONGO-AYLEN LAKE OCCURRENCES

From Kearney the writer proceeded eastward across Algonquin park (where prospecting is not permitted by the Ontario Government) and examined the mines and pegmatites in the vicinity of Opeongo and Aylen lakes. These places are flag stops on the Grand Trunk railway between Madawaska and Barry Bay. Hotel accommodation may be had at Barry Bay or Madawaska.

In this district two dykes have been worked for feldspar, and from another dyke on the Aylen Lake peninsula 60 or 65 tons of mica is said to have been obtained. Claims have been staked from time to time for feldspar or mica, but no radioactive minerals had been noted in the district, and apparently no prospecting for such minerals has been done. Thanks to the kindness of Mr. F. G. Armstrong of the Opeongo Lumber Company, the writer was enabled with a minimum of time and trouble to see a large number of dykes, and radioactive minerals in small amounts were discovered in many cases and some indications of their presence in nearly all cases. A hurried examination of the specimens collected has not so far disclosed any uraninite, but some of the specimens show a considerable alpha-ray activity. The district appears to be favourable for the production of feldspar and mica. Granite pegmatites of all types occur, including the segregated type described in some detail under the Butt Township occurrences. Dykes of this type, carrying the highest grade of crystal potash spar, were seen. Garnet granite-gneiss, biotite, and hornblende-schists and basic irruptives occur, as at Parry Sound and in Butt townships. No crystalline limestone was noticed.

CRAIGMONT-BURGESS OCCURRENCES

A few days were spent in Craigmont and vicinity. Here the pegmatites are chiefly of the syenite variety as to composition, being almost quartz free, and of the granitoid type as to structure. The greater part of the corundum produced at Craigmont is said by Mr. E. B. Clarke, manager of the Manufacturers Corundum Company, to have been obtained from such dykes rather than from the nepheline rocks, and this is further evidenced by the old workings. A considerable quantity of dark minerals was collected from the old dumps and alpha-ray tests show that these are mostly radioactive in some degree. Similar minerals were fairly common on the dump of the Burgess mine, and are also radioactive. No detailed examination of these samples has been made.

Some years ago the old concentrating mill burned down, and subsequently a quantity of concentrates which had been in the fire were put through the new mill. Among the heaviest materials coming off the tables was a mixture of lead pellets the size of No. 8 shot or smaller, along with fused sulphides, magnetite, etc., on which Mr. Clarke, probably at the instance of Sir Stopford Brunton, had tests made for radioactivity, first at McGill University and later in the United States. In both cases it was reported to be slightly radioactive. Mr. Clarke kindly presented the writer with a sample of this concentrate and examination under the binocular has revealed a few small grains of material which chemical and alpha-ray tests show to be unquestionably uraninite. From the nature of the dykes one would be inclined to doubt the occurrence of uraninite, but the finding of radioactive minerals on the dump rather favours the possibility.

MABERLEY OCCURRENCES

Orser-Kraft Feldspar Mine. The occurrence of euxenite in this mine was described by W. G. Miller and C. W. Knight.[1]. Mining has continued since then and a large amount of feldspar has been shipped. The dyke is essentially of the graphic type, grading into a somewhat segregated phase at the eastern end, and at

[1] Miller, W. G., and Knight, C. W., 26th Ann. Rept., Ont. Bureau of Mines, 1917.

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depth. Nearly all the feldspar produced has gone to makers of household scrubbing powders, but since getting into the segregated parts some first-class crystal spar is being mined which would be suitable for pottery and enamel work. The opening is now nearly 200 feet long, 60 feet wide at the top, and 30 to 40 feet deep. The dyke strikes north 75 degrees east magnetic and dips slightly to the south.

Euxenite has been fairly abundant during the whole period of mining, according to Mr. S. H. Orser. At the time of the writer's visit considerably more euxenite was visible than when the dyke was opened up some years ago. Black tourmaline occurs abundantly in some parts of the dyke, particularly at the western end. In some cases euxenite may be found in the centre of tourmaline crystals, showing that it was one of the earliest minerals formed. The feldspar around the euxenite is a very deep red in contrast with the lighter tints of the spar where it is absent. This deep red of the feldspar, first observed here, is characteristic of all the pegmatite occurrences of radioactive minerals so far found in Ontario, and, when well marked, is an almost infallible indication of the presence of such minerals. The cause of this coloration is under investigation.

During the winter Mr. Orser sorted out a quantity of the red feldspar containing euxenite, and submitted it to the Ore Testing Division for concentration. The particulars of this test have been supplied by W. B. Timm, Chief, Division of Ore Dressing and Metallurgy, and may for convenience be given here:

Test No. 159

"A shipment of euxenite ore weighing 1,593 pounds net was received on November 29, 1921, from the Orser-Kraft Feldspar, Limited, Box 266, Perth, Ont. The ore came from the company's property at Maberley, Ont., and consisted of fair-sized crystals of black euxenite in red orthoclase feldspar.

It was desired that the euxenite be separated from the feldspar and that both be recovered in the form of clean products.

A number of specimens were picked out of the ore and the remainder was reduced in a jaw crusher to ¾ inch.

Product	Weight, pounds	Per cent of pounds
—¾ inch	1,582·00	99·80
Loss	3·25	0·20
Heads	1,585·25	100·00

The ¾-inch material was crushed in rolls and then screened on 12 mesh by a shaking Ferraris screen, the oversize from the screen being fed back to the rolls until it all passed through the screen.

Product	Weight, pounds	Per cent of heads
—12 mesh	1,472	92·86
Loss	110	6·94
—¾ inch	1,582	99·80

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The −12 mesh material was sized on a Keedy sizer into four sizes: −8+20; −20+42; −42+86; and −86.

Product	Weight, pounds	Per cent of heads
−8+20	394·0	24·86
−20+42	535·5	33·78
−42+86	260·5	16·43
−86	267·0	16·84
Loss	15·0	0·95
−12 mesh	1,472·0	92·86

Each of the four sizes from the Keedy sizer was tabled separately on a large Wilfley table, so as to make a euxenite concentrate and a feldspar tailing of each size. These products were collected as they came from the tables in long settling boxes. The water from the tailing box was pumped to a callow cone during the tabling of all the different sizes, and by this means a certain amount of slime was removed. After tabling all products were dried and weighed. The four concentrates produced were very good, being nearly all euxenite, with only a small percentage of feldspar. The tailings were composed of clean feldspar. The slime from the Callow tank was very fine, and drab in colour, and under the microscope was seen to be made up mostly of feldspar with a little euxenite.

Product		Weight, pounds	Per cent of heads	
Concentrate	−8 20	14·00	0·89	
"	−20 40	23·50	1·48	3·67
"	−42 86	10·50	0·66	
"	−86	10·12	0·64	
Tailing	−8 20	370·00	23·34	
"	−20 42	504·00	31·79	83·45
"	−42 86	244·00	15·39	
"	−86	205·00	12·93	
Slimes		42·00	2·65	
Loss		83·88	2·14	
Feed to table		1,457·00	91·91	

The concentrate, after sampling, and a sample representing in proper proportions the combined four sizes of tailings, were shipped to the Orser-Kraft Feldspar, Limited, Perth, Ont.

Summary and Conclusions. The euxenite concentrate produced equals 3·67 per cent of the ore treated.

The feldspar tailing product equals 83·45 per cent of the ore treated.

The slimes produced equal 2·65 per cent of the ore treated.

The loss in treatment equals 10·23 per cent of the ore treated.

A good separation of the euxenite from the feldspar can be made. Good clean products can be produced.

Dry crushing and tabling is a very suitable method of treating the ore, as submitted."

Samples of the various concentrates were mixed in the proper proportions to represent the whole, and on analysis yielded the following results:

	Per cent
U_3O_8	5·7
ThO_2	2·30
Cerium group earths	0·48
Yttrium group earths	16·31

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A more complete analysis is being made, the above results being of a preliminary nature. The concentrate contains in addition large amounts of columbium, tantalum, and titanium, besides iron, alumina, silica, sulphur, phosphoric acid, and other common elements. Several rare minerals are present, one of which is probably xenotime.

Ground samples of the tailings and slimes were tested in the alpha-ray electroscope against the analysed concentrate with the following results:

Tailings.....alpha-ray activity practically nil
Slimes.....alpha-ray activity $\frac{1}{178}$ that of concentrate

The slimes, therefore, carry about 0·04 per cent of $U_3O_8 + ThO_2$ or about 0·03 U_3O_8 and 0·01 per cent ThO_2, and the separation from the tailings is practically 100 per cent complete. Thus on a ton of 2,000 pounds the recovery was 73·4 pounds of concentrates containing 4·18 pounds U_3O_8 and 1·68 pounds ThO_2, and 53 pounds of slimes containing 0·02 pounds U_3O_8 and ThO_2. The ore, therefore, carried about 0·2 per cent U_3O_8 and 0·08 per cent ThO_2.

The results of this test on the whole have been encouraging. The recovery has been excellent. The tailings constitute a feldspar product of saleable quality due to the elimination of iron-bearing impurities and their increased value might on the commercial scale pay for the cost of treatment.

Radioactive minerals were found in small quantity in several other dykes in the Maberley district. Some nuggets of euxenite an inch or more in diameter were seen in a large detached block of a dyke on the same lot as the Orser mine. Between Sharbot lake and Kingston on the Kingston and Pembroke railway, especially around Verona and Tichborne, is probably the most active feldspar mining district in Ontario. Most of the mines were visited, but radioactive minerals are apparently of rare occurrence in this district. The specimens collected here have not yet been tested. They are mostly small, and, probably in many cases, are allanite.

GENERAL CONCLUSIONS

The pegmatites of Ontario undoubtedly contain, in the aggregate, a relatively enormous amount of radium and thorium minerals, but these occur in a widely disseminated condition, and, to the writer, it appears improbable that rich concentrations will ever be found in commercial amount in this type of occurrence. Low-grade ore containing a pound or two of uranium oxide to the ton might, nevertheless, under certain conditions, prove workable, the tailings constituting a refined ground feldspar product that would be the main source of revenue, while the uranium minerals would be a by-product obtainable, probably, at little extra expense. It would unquestionably pay producers to market their feldspar in the ground condition. The application of a concentration process would remove not only the radium minerals, but also various highly objectionable impurities such as magnetite, ilmenite, pyrite, tourmaline, black mica, etc., thus improving the quality of the feldspar product, and enabling deposits to be worked on a large scale with little or no expensive hand-picking and sorting. The presence of some quartz in such a feldspar product would, probably, not be objectionable for most uses, provided uniformity of composition were maintained, and this can be done easily by working on a large scale.

Such operations, however, could probably be successfully carried on only by a company with capital sufficient to produce and market ground feldspar in large quantities, mine mica, and recover and refine the rare mineral by-products.

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GEOLOGY OF LEMIEUX TOWNSHIP, GASPE COUNTY, QUEBEC

By F. J. Alcock

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INTRODUCTION

Gaspe peninsula was the scene of the first work of the Geological Survey, Canada. The founder of the Survey, Sir William Logan, explored it for coal. His assistants mapped a number of its rivers. In more recent years detailed stratigraphical work was carried out along its eastern coast. The interior, however, has to a large extent remained an unprospected region, chiefly on account of the difficulties of travel and supplies. The discovery in 1910 of zinc and lead deposits near the headwaters of Berry Mountain brook, a tributary of Cascapedia river, revived interest in the mineral possibilities of the peninsula, and the development of these deposits led to a demand for more detailed knowledge of the geology of the surrounding area. The present report is the result of work during the field season of 1921, with the new zinc and lead field as a central point.

FIELD WORK

A transit and stadia control was carried up the road from bench-mark 1309·95, 3 miles south of the Federal mine. This bench-mark was derived from the surveyed line between Matane and Gaspe counties. The elevations were all derived from this control. The detailed map around the Federal Zinc and Lead mine was made by plane-table and alidade; the areal map was compiled from traverses made with chain, compass, and barometer away from the transit and stadia control lines. Barometer readings were corrected daily from the records of a camp barometer. The trail from the Federal mine to lake Ste. Anne, a trail along Brandy brook, another down Ste. Anne river, and still another up the valley to the southwest of lake Ste. Anne were most useful as controls for the side traverses.

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ACKNOWLEDGMENTS

The writer is indebted to the officials of the Federal Zinc and Lead mine for their courtesy and kindness in facilitating the work in every way in their power. Since no underground work had been done recently the lower level of the mine was filled with water and at considerable expense to themselves, the company had this pumped out so that all the workings might be examined. To Mr. J. C. Beidelman, Vice-President and General Manager of the Company, special thanks are due for the generous gift of specimens, information concerning the mine and surrounding country, the use of mine buildings, maps, mine plans, reports, etc., and for other courtesies extended to the writer.

Assistance in the field was efficiently rendered by P. G. B. Gilbert and H. R. Cromwell.

LOCATION AND AREA

The area (Figure 6) comprises approximately 70 square miles and lies in the central part of Gaspe peninsula on the divide between the waters flowing about 25 miles (as the crow flies) north to the St. Lawrence and those flowing south about 40 miles (as the crow flies) to Chaleur bay. The area, though nearer the St. Lawrence, is more easily reached from the south, by which route Shickshock mountains are avoided.

MEANS OF COMMUNICATION

The Quebec Oriental railway follows the south shore of Gaspe peninsula eastward from Matapedia on the Intercolonial railway. A wagon road 45 miles in length connects Cascapedia, on the Quebec Oriental, and the Federal mine. The road, for 35 miles, follows the east bank of Cascapedia river and then skirts the west side of Berry Mountain brook. For most of the distance the road follows an old lumber road, but so much work has been done by the Federal mining company in improving the grade, building bridges, etc., that the present road is practically a new one. Much work still remains to be done, however, before it can be used for extensive summer transportation.

Camps are situated at convenient intervals along the road. The first is at Escuminac 5 miles above Cascapedia station. A survey of the road made for the Federal company begins at the township line between New Richmond and Flahault, which crosses the Cascapedia one mile above the company's buildings at Escuminac. The other camps along the road are: Joe Martin camp near milepost 10; Tracadie near milepost 15; Douglas at mile 19; Falls near mile 25; Berry Mountain near mile 30; and Woodmans near milepost 35. Milepost No. 40 is at the Federal mine. These camps afford bunkhouses and stables. A trip either way takes from two to three days according to the load and the condition of the road.

Much of the distance can also be covered with canoes. The Cascapedia is swift and contains a number of rapids, but canoes can be poled to Berry Mountain brook and up the Salmon and lake branches. Berry Mountain brook is too small for canoe travel. The lumber companies tow their supplies with horse teams up the Lake and Salmon branches. Scows can be taken in this manner as far as Loon lake on the Lake branch, and up to nearly the headwaters of the Salmon branch. In descending the Cascapedia all the rapids can be run by both scows and canoes.

HISTORY

Small deposits of zinc and lead ores were known at Grand Grève and other points on the coast in very early days, and attempts to mine the deposits were made. They proved, however, too small to be of commercial importance. More recently, reports of the discovery of gold, copper, lead, and zinc in the interior of Gaspe were circulated, but it was not until 1909 that any noteworthy discovery was made. In that year several prospectors found considerable quantities of lead ore on a hill near

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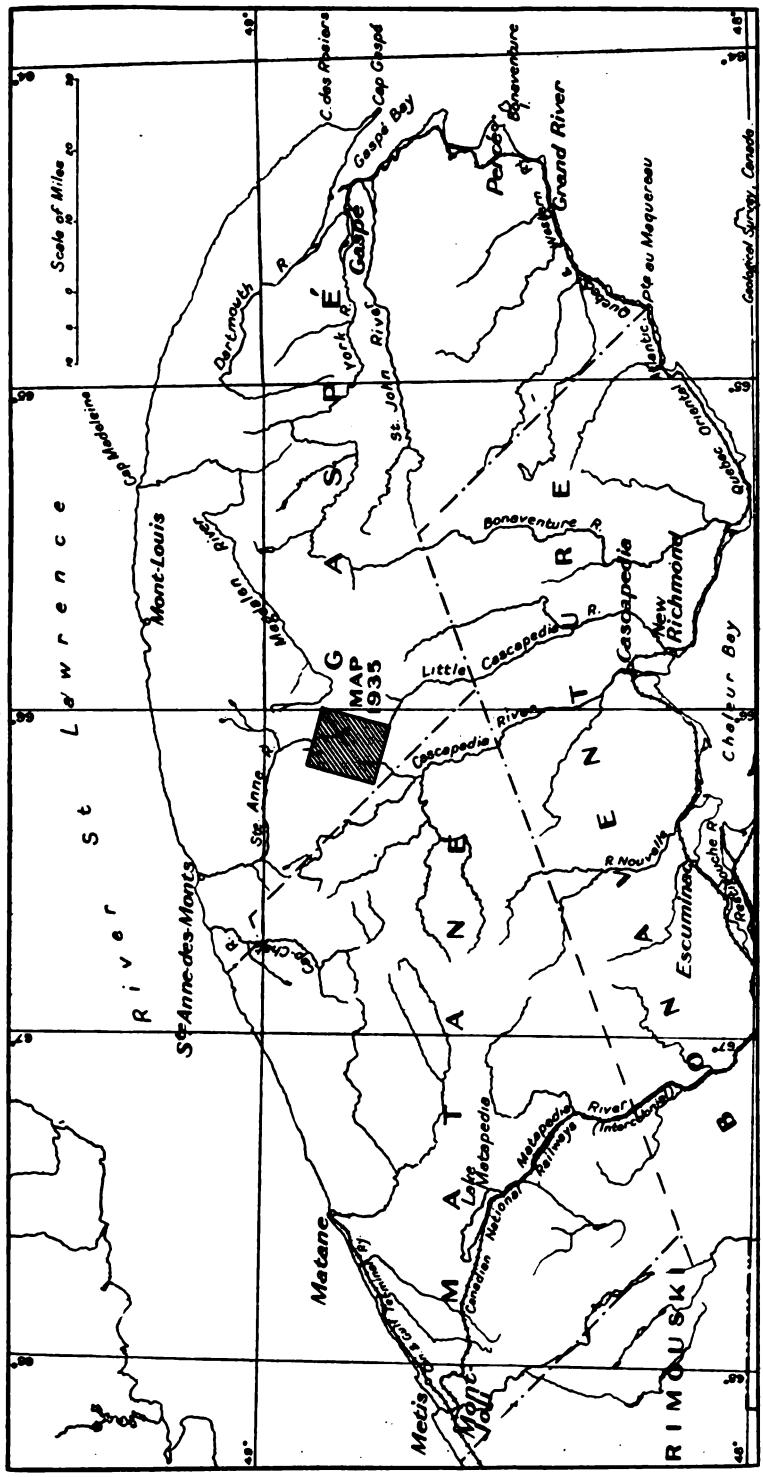

Figure 6. Index map showing location of map-area, Lemieux township, Gaspe county, Quebec.

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Berry Mountain brook, on the site of the present Federal mine. In the following year James McKinley staked the hill and proceeded to search for the lode from which the fragments of lead ore had come. Since then many claims have been staked in the vicinity; those that have been Crown-granted are shown on the areal map. These claims are now held by two companies, the Federal Zinc and Lead Company and the North America Mining Company.

PREVIOUS WORK

In 1843 Sir William Logan explored the coast of Gaspe from Gaspe bay to Paspebiac, travelling along the shore with a canoe and one helper, walking most of the way, climbing cliffs, examining rocks, collecting fossils and rock and mineral specimens, and making a pace and compass traverse of the entire distance. He continued this work the following summer with a larger party. The north shore of Gaspe was followed from cap des Rosier to Cap-Chat river. This river was ascended in canoes and from its headwaters Logan struck through the woods and reached one of the tributaries of the Lake branch of the Cascapedia. Three canoes were built of spruce bark and in them the Cascapedia was descended to its mouth. A micrometer and compass survey was made of this traverse, several of the adjacent mountains were climbed, and a great deal of geological information was obtained. In the autumn of the same year Alexander Murray, who had accompanied Logan on this trip, proceeded eastward, and mapped Bonaventure river for 53 miles. Logan continued the examination of the Gaspe coast westward and ascended Matapedia river as far as lake Matapedia. In the following year Murray explored Matane, Ste. Anne, and St. John rivers. In 1857, J. Richardson ascended Magdalen river; in 1858 Robert Bell examined York and Dartmouth rivers. The results of these surveys were incorporated by Logan in his report of 1863 on the geology of Canada. The work of Logan and his assistants demonstrated the absence of payable coal in the peninsula and in a large way solved the major problems of stratigraphy and structure.

In the years 1882 and 1883 more geological work was carried out by R. W. Ells and A. P. Low. In 1882 Ells examined the coast and the rivers of Gaspe basin. In 1883 he mapped Bonaventure river and the Salmon and Lake branches of the Cascapedia. In 1883, Low ascended the Ste. Anne to lake Ste. Anne and mapped much of the region from the summits of mount Albert and Tabletop mountain. He also surveyed the Middle branch of Magdalen river. These traverses gave much new information concerning the interior of the peninsula. Later in the season Low made a complete traverse across the peninsula by ascending Ste. Anne river to lake Ste. Anne, making a portage of 3 miles from the south end of the lake to the west branch of Little Cascapedia river and descending that river to its mouth.

In 1902 and 1909 Ells examined parts of the peninsula in connexion with oil and oil-shale possibilities. His reports on both of these were unfavourable.

In 1908 J. M. Clarke, of the New York State Geological Survey, published the result of a number of years' work on the eastern coast of Gaspe. Clarke describes the stratigraphy and structure of these Silurian and early Devonian rocks and their immense fossil fauna. The great number of plates and the descriptions of the numerous species make this work a noteworthy contribution to Canadian palæontology.

During the summers of 1917 and 1918 Professor A. Mailhiot of L'École Polytechnique of Montreal, mapped an area of which the Federal mine is the central point. His report on the geology of this area was included in the annual reports for 1917 and 1918 of the "Mining Operations in the Province of Quebec".

Robert Chalmers made studies of the Pleistocene geology of Gaspe, and, more recently, Professor A. P. Coleman of the University of Toronto spent two seasons investigating the glacial history of the peninsula. The result of his investigations has recently been published as Bulletin 34 of the Geological Survey.

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GENERAL CHARACTER OF THE DISTRICT

TOPOGRAPHY

Regional Character. Gaspe peninsula comprises that part of the province of Quebec which lies south of St. Lawrence river and east of Matapedia river. It has a length in an east and west direction of about 150 miles and a greatest width of 85 miles. It is a region of Appalachian structure, consisting of Palæozoic rocks, whose structural trend is a curved line paralleling in a general way the north shore of the peninsula. Its northern coast rises abruptly from the St. Lawrence. In places steep cliffs 800 to 1,200 feet high terminate abruptly at the shore. At other places, as at the mouth of Marsouin river, the hills are only 200 to 400 feet in height, but, less than 6 miles inland, flat-topped ridges reach elevations of from 2,500 to 3,000 feet. The eastern end of the peninsula is marked by bays and cliffs. The cliffs are abrupt terminations of Appalachian folds which have been truncated by marine erosion. The southern coast along Chaleur bay shows an alternation of low rock cliffs, bays, bars, and beaches. This is the important agricultural part of the peninsula.

The interior of the peninsula is a plateau (Plate III A) dissected by deep valleys. The higher points lie along a central axis known as Shickshock mountains. Some of the elevations on this range rise to over 4,000 feet and form the highest land of eastern Canada. A good idea of what this high country looks like from one of the highest elevations can be got from the panorama made by A. P. Low from the summit of mount Albert[1]. The most striking feature is, probably, the mature character of the upland topography. Here and there projections rise above the general level, but on the whole there is a remarkable accordance of summit levels, and the sky-line is comparatively even in all directions. The various individual mountains also show this flat-topped character. Mount Albert, composed of serpentine, has a treeless, rock-strewn, flat surface on which Low in 1883 chained a base 3¼ miles long for triangulation purposes. Tabletop mountain shows a low, rolling topography developed on granite. Its surface is an undulating plateau dotted with numerous lakes and with a few peaks, some of which are 500 feet above the general summit level. Many of the other mountains show similar broad, flat tops. The country is folded, faulted, and intruded, and is made up of rocks of varying degrees of hardness and resistance to erosion, such as soft shales and limestones, hard, massive, volcanic rocks, granite, porphyries, serpentine, and metamorphic schists and gneisses. The truncation of a folded region of such diverse rocks to form a uniform plane like the present surface is to be explained only by base-levelling. Gaspe peninsula, therefore, is a region which must have been base-levelled and, later, uplifted and dissected.

The peninsula contains no rock formations younger than the Palæozoic and the age of this erosion surface can, therefore, only be inferred. The valleys (Plate III B) afford the best guide to the date of the present cycle. Throughout the peninsula they are in a stage of youth. Slopes are uniformly steep, in many places at the angle of repose of the rock debris. Slope angles of 35 degrees are common. Vertical cliffs are frequent where basalt forms the bedrock. A youthful topography, represented by these steep-sided valleys, is superimposed upon the old age topography of the upland

[1] Geol. Surv., Can. Rept. of Prog. 1882-83-84, pt. F.

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surface. The valleys—with the probable exception of certain narrow canyons—are clearly preglacial, for many of them contain glacial deposits, but their youthful condition proves that they cannot be older than Pliocene. It is to be concluded, therefore, that the uplift of the region and cutting of the new valleys dates from Pliocene time.

The character of the uplift may to some extent be deduced from the present elevations of the old base-levelled surface. The point of greatest elevation is on Tabletop mountain whose summit is over 4,300 feet. Some of the other peaks exceed 4,200 feet, but the average elevation of the flatter part of the mountain is about 3,600 feet. Mount Albert has an elevation of 3,600 feet, mount Logan 3,700, and the other high mountains of the central belt run from 3,200 to 3,400 feet. The elevation of the plateau along the central axis of the peninsula may, therefore, be taken as about 3,400 feet, with the granite knobs of Tabletop mountain as monadnocks on the old erosion surface. At the Federal mine, and at Berry mountain, near the junction of Berry Mountain brook with Cascapedia river, the plateau has an elevation of about 1,900 feet. On the coast at Percé, mount Ste. Anne has an elevation of 1,200 feet. The plateau, therefore, has a decided slope to the sea. The uplift at the initiation of one of the cycles of erosion must, therefore, have been differential in character, with the maximum rise along the central axis of the peninsula.

The region stands high at present, but that in Pliocene time it must have stood higher is evident, for the valley of the St. Lawrence extends 200 feet below sea-level. Hence, although there has been uplift in post-glacial time—as is shown by raised beaches—it has not been sufficient to offset the depression that took place during the Pleistocene.

Relief of the Map-area. Mount Lyall, the highest point in the map-area, has an elevation of 3,100 feet. Its flat top shows a remnant of the old peneplain surface. Another remnant with an elevation of 3,000 feet lies southwest of lake Ste. Anne. Northeast of the lake the country reaches about the same elevation, but shows a greater degree of dissection. These higher parts consist of granite and volcanic rocks, the hardest rocks of the region. Northwest of lake Ste. Anne, the plateau country is developed in limestone and shale and reaches an elevation of 2,800 feet. The southern part of the map-area shows a decided slope southward to where Brandy brook and the various branches of Berry Mountain brook join Cascapedia river. The greatest difference of relief between adjacent points in the area is 1,700 feet, between the summit of mount Lyall and the surface of lake Ste. Anne. In the southwestern part of the sheet the average difference of elevation between the valley bottoms and the high, flat areas between the streams is about 600 feet.

Drainage. The map-area lies on the divide between three river systems: the Ste. Anne, which flows to the St. Lawrence, and the Grand Cascapedia and the Little Cascapedia which flow south to Chaleur bay. The area includes all the headwaters of the north branch of Berry Mountain brook. None of the streams is large enough for canoes, except the Ste. Anne at highwater. They all are swift. The average fall of the part of the Ste. Anne shown on the map-sheet is approximately 50 feet to the mile, that of Berry Mountain brook and Brandy brook about 150 feet to the mile, and the tributaries of these show a still steeper gradient.

Some of the valleys of the western part of the sheet are dry during the summer. Brandy brook itself was quite dry a short distance above where the trail from the Federal mine enters its valley. South of this point, however, there was a good volume of water which must have been supplied from underground.

The valleys have an average depth of about 600 feet and, as a rule, show steep slopes. The characteristic topography is flat interfluvial areas with abrupt descents to the streams. Valley slopes of 35 degrees are common. Steep cliffs are frequent where the bedrock is volcanic. Typical examples are seen along Brandy brook, and along the southwest side of lake Ste. Anne. West of Ste. Anne river is a very steep rise to the summit of a granite hogback. Small canyons occur locally, as in the

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limestone in the northwestern part of the map-area, and in the volcanic rocks at the Narrows on Berry Mountain brook.

Lake Ste. Anne is a narrow body of water 3½ miles long which drains northward by Ste. Anne river to the St. Lawrence. It consists of three parts separated by narrows, caused by side streams which have built deltas out into the lake. The narrows between the north and middle parts of the lake is so shallow that even light canoes can be got through only with difficulty. The maximum depth in the northern expansion is 48 feet; the middle part has a depth of 18 feet; the southern expansion, where the shores rise steeply on either side, has a depth of 113 feet. Low states that at one point the lake is over 120 feet deep.

The present drainage of lake Ste. Anne is physiographically abnormal. The side streams which enter the lake, and the part of Ste. Anne river immediately below it, run in a general southeast-southwest direction, suggesting that the normal drainage of the valley occupied by the lake should be southward rather than to the north. Below Ste. Anne lake outcrops of basic volcanic rocks border Ste. Anne river, showing that in several places solid bedrock forms the bed of the stream. At one place 1¼ miles below lake Ste. Anne solid rock can be traced entirely across the stream channel, at an elevation of only 80 feet below the surface of lake Ste. Anne. The valley occupied by the lake—which has a depth of 120 feet—could not, therefore, have been cut by a stream flowing north along the present course.

The topographic map explains these abnormal features. South of lake Ste. Anne, the valley occupied by the lake continues in a direct line to Little Cascapedia river. The divide between the lake and the Little Cascapedia is very low—not more than 10 feet above the lake—and consists of loose material with no rock outcrops. The Little Cascapedia, where this valley joins it, is 130 feet below the level of lake Ste. Anne, or below the lowest part of the lake bottom. It is, therefore, apparent that lake Ste. Anne was once simply a valley occupied by one of the headwaters of Little Cascapedia river.

This diversion took place in Pleistocene time and its cause was a dam of ice and glacial debris from a cirque on the west side of the valley south of the present lake Ste. Anne. The waters of the lake were raised by this dam until an outlet was found over the divide to one of the tributaries of Ste. Anne river. This divide was, probably, between mount Albert and Tabletop mountain. Here the Ste. Anne now flows through a gorge with vertical walls 200 feet high, and at one point drops 60 feet. This gorge which in one place is less than 6 feet wide has most probably been cut since the diversion by the increased flow northward which the change in the direction of flow produced.

The topographic map (No. 1936) also shows that there were minor changes accompanying this major drainage change. The stream entering Ste. Anne river from the west, 2½ miles below Ste. Anne lake, cuts through a limestone canyon which has vertical walls. This stream drains three other streams that originally flowed southwest through a large valley with fairly mature slopes and now occupied by a very insignificant stream. Similarly the stream that is east of—and makes a sharp northwest turn to join—the Ste. Anne, at one time flowed along a course now occupied by four small lakes northeast of lake Ste. Anne.

GLACIATION

Coleman[1] showed that the high interior of Gaspe was not overridden by the Labrador ice-sheet. There are no glacial deposits above 2,500 feet. The tops of the higher mountains (Plate IV A) are rough and irregular in detail with minor irregularities and projections which could not have withstood a continental glacier; moreover, the loose rock debris consists of the same material as the solid bedrock. The region, however, was occupied by local glaciers which spread out chiefly to the south, north, and northeast.

1 Geol. Surv., Can., Bull. 34.

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The map-area shows little sign of extensive glaciation. Over most of it the float, or rock debris, can be taken as an indication of the bedrock. The top of mount Lyall, and the mountain northeast of lake Ste. Anne, and the hogback in the northwest corner of the area are all covered with loose fragments of the same material as the bedrock. There are, however, a few foreign boulders among the rock debris on the hogback west of Ste. Anne river, the presence of which is not so readily explained. These may be residual.

The map-area does, however, show evidence of local glaciation. Along the west side of lake Ste. Anne a large well-developed double cirque forms two big amphitheatre-like hollows on the flank of mount Lyall. The walls in places are steep cliffs, and the top of mount Lyall is a mere knife-edge. Other smaller hollows representing less perfectly developed cirques occupy the valley of lake Ste. Anne.

Large erratics are met here and there as, for example, porphyry boulders on Federal hill, and a huge boulder weighing tons (apparently Precambrian quartzite) on the old road up the hill. These erratics were certainly transported by ice.

SUMMARY OF PHYSIOGRAPHIC HISTORY

Part at least of the physiographic history of Gaspe peninsula from Palæozoic time can be inferred even if a complete record must remain unknown. In Middle Devonian time the country was mountainous, probably rivalling the present Alps and Rockies. From then the history of the region has been one of denudation. How many cycles of erosion the region has passed through since the Devonian it is impossible to state, but sufficient denudation has taken place to uncover and incise a granite batholith. Probably in Mesozoic and Tertiary times the region was more than once reduced to base-level. Certainly in Tertiary time a very perfect peneplain existed in the peninsula with a low divide down the central axis. At that time the lofty mountains of the Devonian were represented only by low monadnocks. In Pliocene times there was uplift. The streams were rejuvenated and valley cutting began. The present elevation of Shickshock mountains, which are to a large extent mountains of denudation produced by the dissection of a plateau surface, is due to the Tertiary uplift.

In Pleistocene time the central part of Gaspe was occupied by local glaciers but was apparently not overridden by the continental ice-sheet. The local glaciers moved down the valleys, disorganized the drainage to a certain extent, and produced local cirques. The history since the disappearance of the ice has been one of erosion with local canyon cutting. Vertical movements in post-Glacial time are recorded by the presence of marine beaches. These show that there has been a rise along the north shore of the peninsula, but the absence on the Chaleur Bay side of any beach corresponding to the very marked Micmac beach on the north coast points to a recent sinking of the southern margin.

CLIMATE, AGRICULTURE, POPULATION AND INDUSTRIES, FORESTS, WATER-POWERS

Weather records have been kept at the Federal mine since August, 1918. The following table summarizes the more important data.

Monthly Mean Temperature

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1918	.....	.....	.....	.....	.....	.....	.....	56	47	39	26	13
1919	8	17	22	33	44	59	60	52	47	33	24	
1920	.....	.....	25	34	45	52	57	60	48	41	15	13
1921	4	5	20	30	47	51	65	53	48	37	18	10

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The lowest temperature recorded was −25 degrees, in January, 1919. January, 1921, saw a temperature of −21 degrees; February of the same year a temperature of −20 degrees. Both the mean and the lowest winter temperatures are higher than on the coast at Gaspe, Father Point, Cap-Chat, etc. The highest temperature recorded —87 degrees—was in August, 1920. July 1919 showed a temperature of 83 degrees; August, 1918, a temperature of 79 degrees.

The following table shows the monthly precipitation at the Federal mine, the snowfall being reckoned as 10 inches of snow to 1 inch of rain.

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1918	.....	.....	.....	.....	.....	.....	.....	2·82	5·58	2·13	2·28	1·85
1919	0·29	2·80	3·10	0·80	1·40	3·50	1·88	2·85	2·24	3·47	3·38	
1920	.....	.....	3·10	2·70	0·72	1·39	10·56	6·43	3·52	6·01	2·93	5·00
1921	3·30	1·20	5·41	0·19	1·25	2·20	2·87	7·14	7·65	4·71	3·55	4·05

The only year for which there is a complete record is 1921, when the total precipitation amounted to 43·52 inches. The incomplete record for 1920 shows over 42·36 inches. Eleven months of 1919 show a precipitation of 25·71 inches. The months in which the greatest amount of rain falls seem to be July, August, and September. Complete snowfall records are available for only two winters. The winter of 1918-19, November to April, showed a snowfall of 86·3 inches: the winter of 1920-21, December-March, had a snowfall of 122 inches.

About two acres of the hill on which the Federal mine buildings are located is planted with vegetables. Potatoes grow to a large size, yield abundantly, and are of excellent quality. The plateau region of the interior of Gaspe seems to be as well adapted for agricultural purposes as the littoral, once the difficulties of communication and clearing the land are overcome.

The population of Gaspe coast along Chaleur bay is engaged in agriculture, fishing, and lumbering. Settlements—both French and English speaking—extend up Cascapedia valley for 6 miles above Cascapedia station. There are no settlements in the interior of the peninsula.

When sinking operations were commenced there were no local men with experience in that class of work and miners were brought from Nova Scotia. Subsequently, however, local labour was employed and a number of men received a training in practical mining.

The country is for the most part well timbered, but the higher summits of the central axis are bare of trees. Other summits support a dense growth of dwarf spruce often not more than 5 feet high but so closely spaced and with their branches so intimately interlocked as to render progress most difficult. The top of mount Lyall is covered for most of its length with this type. Most of the hogback west of Ste. Anne river, and part of the ridge east of Ste. Anne lake, are bare. The valleys and lower interfluvial areas are, however, well wooded. The most abundant tree of the region is spruce, which includes the white, black, and red varieties. Balsam fir ranks next to spruce in importance. Of the deciduous trees, much the most important is white birch which grows to a large size and is particularly abundant on the flat tops of the interfluves. In lower Cascapedia valley, maple, cedar, and black birch are also found.

Lumbering and the preparation of pulpwood form one of the important industries of the peninsula, but in the area under discussion no lumbering operations have been carried on except for the purposes of mining development.

The streams of the area are small. Should waterpower be required for electrical smelting or for other purposes, it could be brought from the Grand Cascapedia where there is throughout the year a sufficient volume.

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GENERAL GEOLOGY

GEOLOGY OF THE PENINSULA

The following is a generalized summary of the rock succession in Gaspe peninsula:

Devono-Carboniferous?	Bonaventure series
	Unconformity
Middle Devonian	Gaspe sandstone
	Unconformity
Lower Devonian	Gaspe limestones
Silurian	Mount Joli massive
	Black Capes section, etc.
	Unconformity
Ordovician	Quebec group
	Unconformity
Precambrian	Metamorphosed sediments and igneous rocks.

Palæozoic igneous rocks: acid and basic lava flows; acid and basic sheets and dykes; peridotites, largely serpentinized; deep-seated acid intrusives.

Precambrian Rocks

The rocks grouped under this head include a series of highly metamorphosed sediments and eruptives. They consist of hornblende and chlorite schists, chloritic slates, grey gneisses often garnetiferous, mica schists, grey quartzites, impure limestone locally interstratified with bands of serpentine, altered limestone-conglomerate, massive chloritic rocks, and epidote-bearing rocks consisting chiefly of quartz and epidote. The age of this series of rocks is not definitely known to be Precambrian, but they are so much more highly metamorphosed than even the oldest of the Palæozoic rocks that it is highly probable that they are pre-Palæozoic.

Quebec Group

The rocks included under the term Quebec group are considered to range in age from Cambrian to late Ordovician. They consist of red, green, and grey shales, black graptolitic shales, grey and green sandstones, grey limestone and limestone-conglomerate. These rocks form a broad band along the St. Lawrence River side of Gaspe peninsula. Another area occurs on the southeast coast in the vicinity of cape Macquereau and Grand Pabos. They were folded locally and suffered erosion before the deposition of the Gaspe limestones.

Silurian

Just how much Silurian is exposed in Gaspe is one of the unsettled problems in connexion with the geology of the peninsula. Considerable areas of the interior have been mapped as Silurian, but, as will be shown later, it is probable that most of these are really Lower Devonian. Undoubted Silurian rocks, however, do occur. At Percé, the Mount Joli massif is Silurian. At Black Capes, also, there is a section showing a thickness of over 7,000 feet of Silurian rocks, the thickest Silurian section in America. The lower strata of this section contain abundant Niagara fossils; the upper part shows evidence of having been deposited—partly at least—under subaerial conditions, and is probably of delta origin.

Gaspe Limestones

The Gaspe limestones of Logan were classed by him as Silurian. Later work, however, has shown them to be Lower Devonian. Clark divides them into three divi-

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sions based on lithological and faunal characteristics. The lowest is the St. Alban beds consisting of calcareous shales; conformably above these are the Bon Ami beds consisting of magnesian limestones and containing but few fossils. The upper member, also conformable to the rest, is the Grand Grève limestone; it contains an abundant fossil fauna of Helderberg-Oriskany types. Logan estimated the thickness of these rocks at 2,000 feet, of which the Grand Grève beds include 600 feet.

Gaspe Sandstone

The Gaspe sandstone covers wide areas of the interior. In fact the areas coloured as Devonian on areal maps of the peninsula really mean this series, and the areas coloured Silurian are largely at least Lower Devonian. The series was stated by Logan to have a thickness of 7,036 feet. It is very homogeneous, consisting of grey, drab, and reddish sandstones with some shaly and conglomeratic beds. Some of the lower beds contain a marine fauna of apparent Hamilton age. Certain horizons contain great numbers of fossil plants, chiefly Psilophyton species. Near the middle of the section there is a bed of coal from 1 to 3 inches in thickness. The Gaspe sandstones are folded up with the Gaspe limestones on the coast. There is apparently, however, a slight angular unconformity between the two series. The fact that in the interior of the peninsula the sandstone series is as a rule less deformed than the limestones, suggests a period of movement between the deposition of the two series. Flows and intrusions of igneous rocks are associated with the sandstones.

Bonaventure Series

Bordering Chaleur bay an horizontally-lying formation known as the Bonaventure series rests unconformably on the older Palæozoic rocks. It is coarsely conglomeratic and its deep red colour makes it a very conspicuous feature of the Gaspe coast. Mount Ste. Anne at Percé and Bonaventure island are composed of this formation. It contains numerous fossiliferous boulders of Gaspe limestones, but its matrix has not been found to contain any fossils from which the age of the series may be definitely determined. It is certainly later than the period of Devonian deformation, and has been classed by some authors as Upper Devonian, by others as Lower Carboniferous. The series has a thickness of at least 1,200 feet.

Igneous Rocks

Flows and dykes of basic composition are numerous in the Gaspe sandstone series. In the interior of the peninsula there are also acid flows, sheets, and dykes, deep-seated acid intrusives represented by dykes and stocks of syenite, and the granite batholith of Tabletop mountain. Three areas of serpentine, also, occur. The largest is the Mount Albert mass, which is 12 miles long and has a greatest width of 3½ miles. A second, forming South mountain, lies about 12 miles west of mount Albert. It has a length in an east and west direction of about 2½ miles and a width of ⅝ mile. A third and smaller area is found on Dartmouth river. These rocks are apparently intrusive into the sedimentary rocks of the region and hence are post-Lower Devonian in age.

GEOLOGY OF THE MAP-AREA

The consolidated rocks of the map-area consist of sediments, volcanics, and intrusive rocks of both hypabyssal and deep-seated varieties. The following is the succession:

Porphyry, granite, syenite
Intrusive contact
Gaspe sandstone
Basic and acid volcanics
Shales and limestones

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Shales

The oldest rocks in the vicinity of the Federal mine are sediments, which consist largely of shales exposed in several of the stream beds, in cuttings for the mine roads, in prospect pits, and, best of all, in the underground workings. The shales vary from grey and greenish to black; weathered fragments are commonly light grey. They frequently show a distinct colour banding, each band differently tinted. The beds are mostly thin, varying from a fraction to an inch to over 6 inches. Small amounts of sandy material are interbanded with the argillaceous beds. Limestone beds and calcareous shale horizons are numerous. In places the limestone associated with the shales is black and contains abundant crinoid stems. Near the mine the strike of the sediments varies considerably but has a general east and west direction, with a dip to the south of from 30 to 70 degrees. The shales have been broken up by earth movements. In places breccias composed of angular fragments of all sizes and shapes are formed; in other places the beds are finely jointed and, locally, even a cleavage is developed across the bedding planes.

Limestones

As already mentioned limestone is found interbedded with the shales at the Federal mine. This variety is massive, dark grey to black, and weathers brownish. From the hill on which the mine bunk-house is built the following fossils were collected:

Crinoid stems
Cœlospira concava
Meristella cf. *champlani*
Leptostrophia blainvilli

From a boulder in the brook at the foot of the hill *Fenestella* and crinoid stems were collected.

The sediments in the northern part of the map-area are dominantly limestones, and are well exposed on nearly all the streams. In places vertical cliffs 50 to 100 feet high are to be seen. The rock consists of grey limestone, thin to thick bedded, and locally fossiliferous.

An outcrop west of the Ste. Anne trail supplied the following fossils:

Atrypa reticularis
Spirifer murchisoni
" *gaspensis*
" *arenosus*
Orthothetes (Schuchertella) becraftensis
Actinopteria sp.
Lentaculites elongatus
Phacops logani

Kindle reports that this fauna represents an early Devonian horizon. Probably all the forms collected are from the Bon Ami and the Grand Grève limestones, subdivisions of Logan's Gaspe Limestone series.

Limestone outcrops on the streams that join Ste. Anne river from the southeast below lake Ste. Anne. The beds average 2 or 3 inches in thickness. There is only a little shale but a great deal of sandy rock, and at one place sandstone is abundantly interbedded with the limestone. A fragmental rock, also, of apparently pyroclastic origin, was found at a point about 3,000 feet east of the Ste. Anne.

Gaspe Sandstone

The southwestern part of the map-sheet is covered by a greywacke formation which is equivalent to what on the coast has been termed the Gaspe sandstone. In this area it rests on a thick mass of basic volcanic rocks which will be described subsequently. The series is coarse, in places conglomeratic. It varies from green

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and drab to reddish. It apparently consists partly at least of weathered volcanic material. It is coarsely bedded and locally crossbedded. Some of the finer layers show ripple-marking. A few fossils collected from the area proved to be brachiopods and lamellibranchs. The lower horizons of this series on York river contain an abundant fauna which has been described by Clark. Kindle, reporting on the writer's collection, says the fossils represent a Hamilton horizon but include a few Oriskany forms which are apparently survivals of an early Devonian sea and came from another region. In an outcrop on the Federal mine road, 2½ miles south of the mine, some fossil plant remains were collected on which W. A. Bell reports, "The plant material is preserved poorly as flattened carbonized residues, and imprints of dichotomously branching stems. They clearly are referable to the Devonian group of Psilophyton Dawson. The stems are smooth or irregularly furrowed, but there are imprints that are definitely costate. No spinous appendages are present as in *P. princeps* var. *ornatum* Dawson, and the resemblances to the stems from Campbellton, N.B., figured by White, are quite close. The latter were included by Dawson in his *Psilophyton princeps*. On the other hand the present stems may be identical with *Psilophyton robustius* Dawson, the poor preservation and the absence of fructifications prohibiting further comparisons."

The beds along the mine road lie horizontally in striking contrast to the folded, faulted, and breciated shales and limestones at the mine. In one of the streams entering Brandy brook there are also outcrops of arkose which lies flat. Here, moreover, are beds containing shale pebbles up to an inch in diameter, mostly rounded and flat and apparently of the same character as the shales found in place at the Federal mine. There appears to be no doubt, therefore, that the Gaspe sandstone of the map-area was deposited later than much at least of the deformation which disturbed the rocks of the region, and that there was also a period of erosion as well as deformation between the deposition of the shales and limestones and deposition of the clastic rocks. The intimate association of the fragmental beds with the flows and dykes of basic rocks shows also that the period in which they were laid down was also one of igneous activity.

As to the origin of the Gaspe sandstone, its invertebrate fossils are marine forms, but are limited to a few horizons and are abundant only in certain beds towards the base of the series. Plant remains are found throughout a much wider stratigraphic range and the forms are Psilophyton, which are now known to be terrestrial plants. The series, therefore, was, apparently, deposited largely under terrestrial rather than under marine conditions. The character of the sediments leads to the same conclusion. The series is dominantly clastic. The beds consist of sandstone which is commonly arkosic and often conglomeratic. One bed of conglomerate described by Logan has a thickness of 156 feet. There are only subordinate amounts of shale and no limestone. The series is probably over 5,000 feet, a fact which in conjunction with the wide areal extent of the series points to a continental origin. The formation is crossbedded and ripple-marked. Its reddish colour suggests deposition under conditions in which oxidation kept pace with accumulation, i.e. subaerial rather than marine. It is probable, therefore, that the series was deposited as deltas and along river flood-plains rather than along a coast or in arms of a sea. At times marine floods may have extended up the valleys.

Part of this clastic material was undoubtedly derived from local volcanic rocks; its lithological character and great thickness, however, suggest that much of it was derived from some granitic terrane which was undergoing erosion. The pre-Devonian rocks of Gaspe, including even the Precambrian varieties, are not such as would give an arkosic type of sediment. The granite batholith of the interior of the peninsula or that of New Brunswick has not as yet been unroofed. It seems necessary to conclude, therefore, that much of the material from which the series was built up was derived from the Precambrian granite country north of the St. Lawrence. If this conclusion be correct, it follows that in pre-Gaspe time the drainage across the

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Gaspe region must have been in a general south or southeast direction. A detailed mapping of the area throughout the entire peninsula with fuller information as to lithology and thicknesses might perhaps determine whether this theory of deposition along north and south lines is correct.

Basic Volcanics

Basic volcanic rocks cover about 60 per cent of the map-area. They overlie the shales and limestones and are in turn overlain by the Gaspe sandstone of the southwestern part of the sheet. Good exposures of these rocks are numerous. They outcrop along the new mine road and the old road along Berry Mountain brook. At what is known as the Narrows, Berry Mountain brook flows through a narrow gorge of these rocks and almost vertical cliffs border Brandy brook at one point. At several places low cliffs border Ste. Anne river. These rocks are the hardest of the region and almost all the abrupt slopes, except a few limestone cliffs, are formed of them. The ridge southwest of lake Ste. Anne, whose summit can just be seen from the Federal mine, consists entirely of these basic rocks.

The rocks present considerable variations. Some are dense and black; others are distinctly porphyritic with laths of feldspar in a dense matrix. Amygdaloidal varieties are seen in a number of localities. Good exposures of this type are to be found on the old mine road and in the Narrows of Berry Mountain brook. Some of the amygdaloidal varieties are also porphyritic. On the graded road about 2 miles south of the Federal mine, a dense black amygdaloidal lava contains numerous phenocrysts of white plagioclase. Many of the amygdules which consist largely of calcite have a greenish border composed of the chlorite, delessite. They are commonly flattened oval masses and some of them reach a length of over one inch. Some of the smaller amygdules are completely filled with delessite. Quartz also serves as an amygdule filling, but in minor amounts. One amygdule 2 inches in diameter was found lined with agate layers and with the interior filled with quartz crystals pointing towards the centre. At one place near the mine road a large erratic composed of basic rock shows good ellipsoidal structure. No similar structure was seen in place, although the rock is evidently part of this same series and of local origin. Some of the flow rocks weather reddish-brown.

Thin sections of the basic rocks show a considerable range of types. The steep slopes opposite the Federal mine consist of a dark, dense rock with small phenocrysts of feldspar. Some of these plagioclase phenocrysts are clear; others contain a great amount of iron ore inclusions. The main mass of the rock consists of augite crystals penetrated in all directions by laths of labradorite. A little olivine is present, partly altered to serpentine. Considerable amounts of chlorite are also present; some of it is dark green with sharp outlines and is apparently primary. Iron ore is present in considerable amounts. It is largely magnetite but a little hematite is also seen. This is the only section studied in which olivine was found to be present. A number of other sections show a typical ophitic texture with no phenocrysts present and with almost all the augite altered to a pale green chlorite. A section from the black volcanic rock at the Narrows shows a similar type, but in addition some small shreds of reddish-brown biotite.

The basic rocks are locally mineralized. In the amygdaloidal variety at the narrows of Berry Mountain brook cubes of galena are found in places in the calcite amygdules. At another place on the mine road small veins of calcite containing galena were found in basic flow rocks.

Acid Volcanics

Acid volcanic rocks occur at a number of places in the map-area. In places they are associated with basic flows and are undoubtedly part of the same period of volcanic activity. In most places it was not found possible to separate the two types

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owing to lack of exposures and to local resemblances of types. For example, certain dense black rocks on close examination are found to have phenocrysts of quartz and under the microscope are found to be quartz-porphyries. One area, however, of a reddish acid volcanic on the top of mount Lyall is so sharply marked off from the underlying basic volcanics that it was mapped separately. On the lower slopes of the same mountain thin flows of grey volcanic rock were found associated with the basic rocks but in exposures too small to be represented on the map.

The acid volcanic on the summit of mount Lyall is a dense yellow to reddish rock containing small phenocrysts of quartz and pink feldspar and is to be classed as a rhyolite. In places it shows good sheet jointing. In thin section the phenocrysts are seen to consist of quartz and orthoclase. Some of the quartz crystals show sharp crystal outlines, others show corroded borders. The feldspar phenocrysts are commonly long, tabular crystals of orthoclase. The groundmass in some sections is a brownish glass, in others it is cryptocrystalline.

The reddish rhyolite that forms the summit of mount Lyall is underlaid by dark-coloured volcanics, associated with which are some acid flow rocks. These acid rocks outcrop at an elevation of 2,100 feet in the beds of streams which flow down the cirque of mount Lyall. In hand specimen the rock is light grey to pinkish. In places it shows banded lines of flow. Other specimens contain small, round or irregularly-shaped, masses of chalcedony. Still others contain vugs filled with agates. In the shallow bay immediately southwest of the second narrows on lake Ste. Anne many agate-filled vugs were collected, some of them over 4 inches in diameter.

In thin section the groundmass of this variety is seen to be cryptocrystalline, and probably represents a devitrified glass. Chalcedony is abundantly present as brownish radiating fibres. Small agate-filled cavities are also to be seen in the section. One of these extends across the section as a long, narrow vein. Small amounts of iron ore are also present. The rock is an acid flow which has been acted upon by siliceous solutions.

Acid Hypabyssal Rocks

Porphyritic rocks of many varieties are found throughout the map-area. Many of them occur as dykes; others of greater size are apparently sills or stocks. In most cases there are not enough outcrops to determine the exact boundaries of these masses or their exact relationship to the intruded rocks. Some of them approach in appearance the rock which forms the summit of mount Lyall and which has been described as an extrusive. They are apparently of the same general composition as this rock and of similar composition also to some of the deep-seated acid rocks which will be described later. They were intruded near the earth's surface, in some places following, in other places cutting across, the structural planes of the intruded rocks.

One of the largest areas forms a hill over 2,300 feet high, about 1½ miles north of the Federal mine. The rock is a dense reddish variety showing phenocrysts of quartz and feldspar. In thin section some of the quartz phenocrysts show crystal outlines, others slightly corroded borders. The feldspar is orthoclase. Pale green hornblende, secondary after either hornblende or biotite, is present and also some iron ore. The groundmass of the rock is microcrystalline consisting of quartz and orthoclase. Numerous dykes throughout the area show similar features. In some the phenocrysts visible to the naked eye consist entirely of pink orthoclase.

Basic Hypabyssal Rocks

As already mentioned, many of the basic rocks show a distinct porphyritic texture. In many cases these types are known to be extrusives because of their amygdaloidal structure and field relationships: some may be hypabyssal intrusives. Many of the sections studied show a coarse ophitic texture characteristic of diabase. Diabase dykes that cut the Devonian and older rocks are known in many places throughout Gaspe peninsula and some of the basic rocks have, probably, intrusive relationships to the older rocks.

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Plutonic Rocks: Granite

The northeastern part of the map-area is underlain by the southwestern part of a granite batholith which forms Tabletop mountain. This batholith, as outlined on the older geological maps of the peninsula, has a length in a north and south direction of 17 miles and an average width of 4 miles. It forms the highest land of Gaspe peninsula and is rather striking in the fact that its longer axis cuts directly across the structure of the sedimentary rocks.

The part of the batholith contained in the map-area is intrusive towards the limestone and the volcanic rocks. The rock is even grained, but locally shows a tendency to porphyritic texture. It varies from grey to reddish and becomes progressively coarser-grained as one progresses from the contact with the intruded rocks towards the interior of the intrusive.

A good exposure of the contact phase of the granite is exposed on Ste. Anne river just below where the river trail crosses to the east side of the stream. The rock is dense and massive, and light grey, resembling limestone in appearance, but holding small crystals of feldspar. In thin section the rock is seen to be distinctly porphyritic. The phenocrysts consist chiefly of orthoclase, but some oligoclase is also present. Some of the orthoclases show sharp crystal boundaries, and Carlsbad twinning is present in many. The feldspars are all partly altered. One large phenocryst of quartz with corroded borders is present in the section. Some pale green chlorite represents the original ferromagnesian mineral, probably hornblende. The section also shows small irregular masses of carbonate which may represent incompletely digested fragments of the intruded rock. The groundmass of the rock is microcrystalline and consists of quartz and orthoclase. Small amounts of iron ore are present.

The hogback west of Ste. Anne river in the northern part of the map-area shows a slightly coarser-grained phase of the same rock. In places it is greyish, in places distinctly pink. Small individual crystals and cleavage surfaces of feldspar, minor amounts of quartz, and small dark specks representing the ferromagnesian constituents can be distinguished in hand-specimens. In thin section the rock is seen to consist of feldspar and quartz crystals in a matrix composed of smaller crystals of the same minerals. The feldspars, which are all more or less altered, consist dominantly of orthoclase but with a little acid plagioclase. Quartz, though fairly abundant as large crystals of irregular outline and as smaller fragments in the matrix, is much less common than the feldspar. The ferromagnesian constituent is hornblende, which is largely altered to chlorite. The rock is on the border-line between granite and syenite.

On the ridge northeast of lake Ste. Anne the intrusive shows a gradual coarsening of grain from the contact with the limestone and volcanics towards the interior of the mass. Away from the contact it has a typical granitic texture. The most abundant mineral is feldspar, comprising orthoclase and albite in about equal amounts. Graphic intergrowths of orthoclase and quartz are also abundant. Quartz is present, but is much less abundant than the feldspar. Hornblende, also, largely altered to chlorite, is present. Iron is an accessory constituent. The texture is fairly even grained and typically granitic.

This batholith appears to have produced but little contact metamorphic effects. No actual contacts between the intruded and the intrusive rocks were observed, but the intruded rocks near the granite intrusions have not been greatly altered.

Syenite

Syenite intrusions occur at a number of places in the neighbourhood of the staked claims. Most of them are linear bodies or dykes; others are of the nature of small stocks cutting the shales and limestones.

In hand specimen the rock is as a rule reddish, due to the presence of orthoclase feldspar. It is fairly coarse grained; individual feldspar crystals reach a length

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of over half an inch. At one place in the dyke immediately northwest of the Federal mine, Carlsbad twins of orthoclase, half an inch in length, can be picked out of the weathered rock. Many of the feldspar crystals are long and lath-shaped. There is no quartz in the sections studied, but considerable quantities of dark ferromagnesian minerals are present.

All the sections of these rocks proved to be badly altered. The freshest was from a specimen collected from the small stock about half a mile southwest of the Federal mine. This is a coarse-grained rock with granitic texture. The feldspar is largely orthoclase. Some striated feldspar of the composition of oligoclase is also fairly abundant. The hornblende is almost all altered to pale green chlorite. One crystal of colourless augite is also present in the section. Both magnetite and pyrite are abundant as accessory minerals.

Serpentine

To the north of the map-area lies a large mass of serpentine through which the south branch of Ste. Anne river has cut a channel. A reconnaissance trip was made to the summit of mount Albert to see this belt of rocks. On the summit the rock is locally banded, but elsewhere it is massive. It weathers to a buff colour, and the weathered surfaces in places show a coarse mesh structure. Freshly-broken surfaces are dark green to almost black, and masses of green olivine can commonly be seen. In places the rock has a coarse fibrous structure due to the presence of picrolite. A little chromite is associated with it, but, so far as has been observed, only in small, widely-scattered pockets.

Sections of specimens collected at elevations of 2,450 feet, 2,700 feet, and 3,200 feet were studied. The first two consist almost entirely of serpentine which has resulted from the alteration of olivine. Only very small amounts of the olivine have escaped serpentinization. A little chromite is present. The section of the specimen from the top of mount Albert shows in addition to the serpentinized olivine considerable quantities of a pale orthorhombic pyroxene, which is probably enstatite. The enstatite is altered along irregular fractures to bastite. This rock corresponds to the harzburgite of Rosenbusch.

Summary of the Igneous Rocks

The igneous rocks of the area are younger than the shales and limestones and hence are post-Lower Devonian. The Gaspe sandstone was laid down in a period of igneous activity. In the area mapped the sandstone overlies thick flows of basic eruptives. In other places it is intruded by dykes of diabase and porphyry. It is probable, therefore, that most of the igneous rocks belong to the Middle Devonian, a period in which both acid and basic rocks were intruded, some at depth, others near the surface, and still others were poured out of craters and fissures and were distributed over the country. Whether all the rocks from the granite to the periodotites were derived from a common parent magma is not known.

STRUCTURE

Gaspe peninsula is a region of typical Appalachian structure, the rocks being thrown into folds and broken by both normal and thrust faults. The structural trend is mainly east and west forming a broad curve which roughly parallels the north shore of the peninsula.

The cross-sections on the map of Lemieux township (No. 1935) show the structure of the area. The Gaspe sandstone and the volcanic rocks have been but little disturbed. The Lower Devonian shales and limestones have, however, been folded and faulted. In the northern part of the area these rocks form a syncline whose axis trends in a general north and south direction. Intrusion of the Tabletop batholith is obviously responsible for this local structure being different from the regional structure of the peninsula.

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ECONOMIC GEOLOGY

LEAD-ZINC

Crown-granted mineral claims of the area (Map 1935) are held by two companies, the Federal Zinc and Lead Company and the North America Mining Company. Almost all the exploration and development work has been carried out by the former company. The president of the Federal company is Mr. T. O. Lyall; the vice-president and general manager is Mr. J. C. Beidelman; the company's headquarters are at 285 Beaver Hall Hill, Montreal.

Character of the Deposits. The deposits are in Devonian shales and limestones intruded by porphyry and syenite. The sediments are folded, faulted, jointed, and brecciated. There has also been movement after the period of mineralization.

The country is covered by a heavy overburden and in consequence outcrops are few. The presence of ore is usually detected by finding pieces of galena in the float. These sometimes form large rounded masses, weathered brownish; as a rule they have not travelled far, and by trenching uphill from such float, vein outcrops can usually be uncovered. In other cases actual outcrops of veins are exposed. Most of these outcrops consist of chambered quartz from which the zinc blende, and often also the galena, has been leached. The quartz is white or perhaps stained brownish; the amethystine variety, common underground, is usually bleached white in the surface exposures.

In the form the deposits are veins, and like most veins they pinch and swell. In some places they show sharp contacts with the enclosing rock, in other places there is a brecciated zone in which there is a more or less gradual transition from massive vein material to barren country rock. In places the latter type becomes a stockworks. Horses of country rock of various sizes and shapes are found in the veins and have sharply-defined borders and angles, showing that the solution which deposited the vein material did not affect the shales.

The dip of the veins is for the most part over 70 degrees. The larger veins run in a general northeast direction, cutting across the strike of the sediments. They apparently follow fault and brecciation planes, with mineralization to a lesser extent along joint planes. In addition there has been movement later than the mineralization. One fault parallels the west wall of the Federal vein, and 180 feet north of the north crosscut, the same vein is cut off on the 100-foot level by another fault.

Mineralogy of Deposits. The minerals of the veins are sphalerite and galena in a gangue of quartz and carbonate. Pyrite, marcasite, and chalcopyrite are present in very minor amounts. The sphalerite is for the most part light yellow, varying locally, however, to a reddish brown, and is almost free from iron. It compares favourably with the best Missouri blende.

An analysis (made by J. T. Donald and Company, Montreal, for the Federal Zinc and Lead Company) of a sample of ore gave the following results:

	Per cent
Insoluble and silica	0·35
Iron oxide	0·82
Alumina	0·10
Sulphur	32·46
Zinc	66·00
Lead	Traces
Lime	None detected
Magnesia	None detected
Cadmium	None detected

In the surface exposures and to a certain extent in the upper parts of the veins the sphalerite has been leached out by surface waters, but the leaching has affected only slightly the amount of zinc blende originally present. Some of the surface specimens have a white coating which consists of an intimate mixture of zinc silicate

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or calamine, zinc carbonate or smithsonite, and zinc hydrated carbonate or hydrozincite. A soft, white kaolin mineral is also found on the 100-foot level, and even on the 250-foot level, but only in small amounts.

On the 250-foot level a greenish-yellow mineral is associated with the zinc ore both in the veins and in the breccia. This mineral was found to be an hydrated silicate of aluminum carrying a smaller quantity of magnesium. The ratios of silica to aluminum and magnesium are as follows: for 12 Si there are 8 Al and 1 Mg; the water ratio was not determined. The mineral when examined under the microscope was seen to consist of low birefringent fibres. The mean index of refraction is 1·566. It does not possess physical and chemical characters sufficiently well defined to place it in the mineralogical nomenclature. It is certainly a mineral of the kaolinite group carrying in addition a small quantity of magnesia.

The galena is less abundant than the sphalerite, but there are places where it occurs in large masses. Being less soluble than the sphalerite, it persists in the upper parts of the vein; and in some of the outcrops it occurs in the quartz, often with a reddish brown coating of iron oxide. The cleavage surfaces range from minute areas to surfaces over 2 inches across. In one vug lined with small crystals of dolomite an excellent galena crystal showing cube faces truncated by octahedron corners was found. Some of the larger masses of galena show strain effects, produced by movement after the periods of mineralization.

The chief gangue mineral is quartz, both white and amethystine. In places the quartz is definitely banded, and frequently there is good comb structure. At one place in the Federal vein there are six of the parallel fillings which show that at least six times the vein was closed and reopened along the wall. The banded veins which show this comb structure in the centre almost always consist of the amethystine quartz. In some places the central bands consist of amethystine quartz, and the outer part of white quartz. Dolomite occurs as minor gangue mineral and a light yellow carbonate of the composition of ankerite is also fairly abundant. On the 250-foot level are numerous small stringers of light pink calcite. Most of these are less than an inch in width and as a rule cross the bedding of the shales at steep angles.

A study of some polished sections of the ore brought out some facts with regard to its paragenesis. A specimen composed largely of dark sphalerite was found to contain the iron sulphides, pyrite and marcasite, of which marcasite was the younger. The latest sulphide introduced was galena which occurs as veins traversing the other sulphides; its deposition was probably in the nature of a replacement. Though essentially belonging to one period of mineralization, there seems to have been a certain order of deposition among the vein minerals, but, undoubtedly, the periods of deposition of all the minerals overlapped. The first period was largely occupied by the deposition of quartz. Then followed iron and zinc sulphides of which marcasite was the latest. Later still came solutions which deposited lead, and, last of all, quartz and carbonate.

Origin of the Deposits. The deposits are believed to be genetically related to the deep-seated intrusive rocks of the area. Siliceous sulphide-bearing solutions from the magma in the later stages of its crystallization probably travelled along lines of fracture for considerable distances from their source and deposited their sulphide and silica content along these fracture planes and in brecciated zones. The shales were the most influential in causing precipitation from solution. Earth movement continued during this period of mineralization. The veins were repeatedly reopened and even after vein deposition ceased, further faulting took place.

Development. Sixteen veins have been exposed by surface workings. Only the main ones have been shown on the map of the region around the mine (Plate IV B). All of these show ore where they have been opened. The main vein, and the best developed, is the Federal or No. 1. It has a known length of approximately 600 feet and an average width of 8 feet. In places it is considerably wider than this and in addition is bordered locally by mineralized breccia. Several other veins intersect it.

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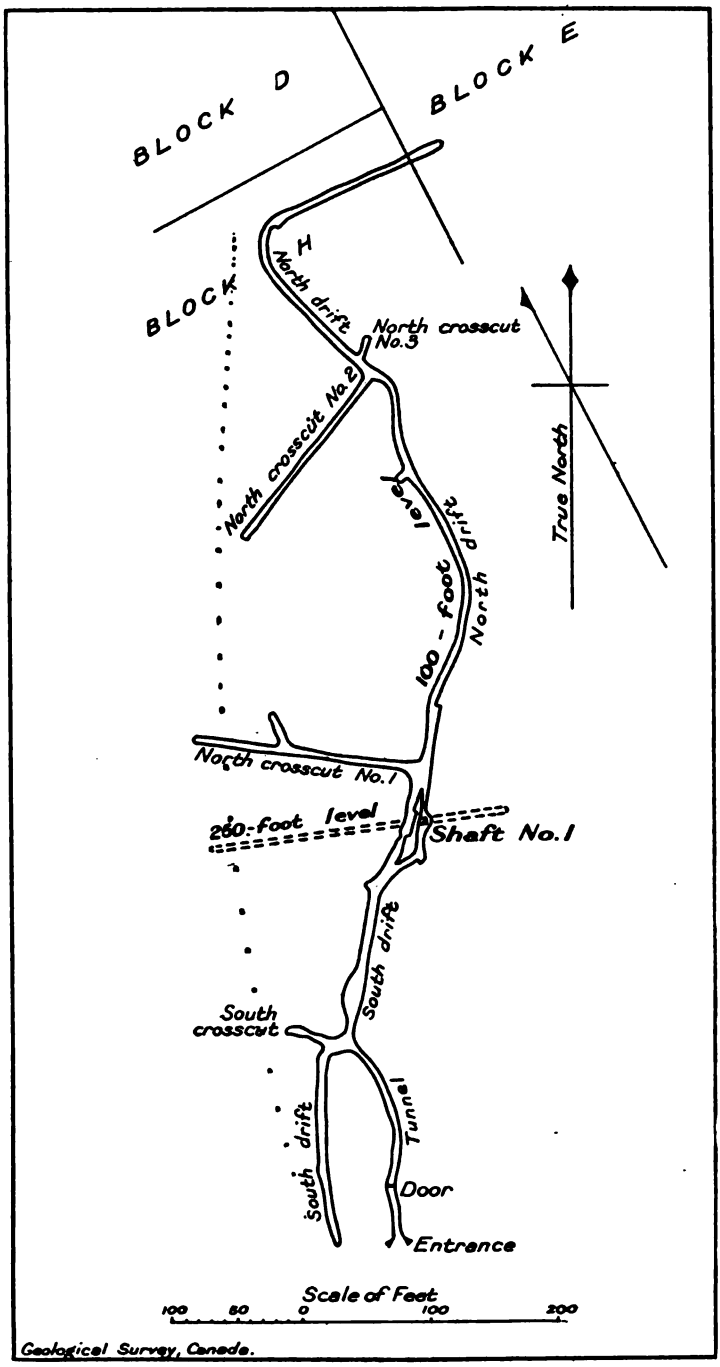

Figure 7. Plan of underground workings, Federal Zinc and Lead mine, Lemieux township, Gaspe county, Quebec.

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With more development it may be found that other veins compare favourably in size and quality with the Federal. Two of these possibilities require mention. The first is the McKinlay, or No. 16, which forms a large, abrupt outcrop on Federal hill 900 feet southwest of No. 1 shaft. This is a large vein whose length has not as yet been determined by trenching, but which is exposed in the road to the east of the main outcrop. It has a width of 60 feet which includes, however, a horse of country rock. The vein contains high-grade ore and is bordered on the north by breccia. The other possibility is No. 14, or the Bois. It has been traced by trenches and sunk on for 64 feet. The vein has a maximum width of 18 feet and shows the usual mineralization, with the local addition, however, of more chalcopyrite than is present in the Federal vein.

Most of the exploration has been carried out from No. 1 shaft on the Federal vein. This was originally sunk 100 feet on an incline following the vein, but later, a vertical shaft was sunk from the surface to a depth of 257 feet. The amount of horizontal workings from this shaft is as follows (*See also* Figure 7):

	Feet
Drifting—	
North drift (100-ft. level)	657·3
Drift from No. 1 west crosscut north (100-ft. level)	34·2
South drift (No. 1 level)	360·8
Drift around Federal shaft (100-ft. level)	73·8
	1,126·1
Crosscutting—	
No. 1 west crosscut north (100-ft. level)	180·4
No. 2 " " north " "	164·0
No. 1 east " north " "	30·9
No. 1 west " south " "	48·0
Adit 100-foot level	126·8
Adit 250-foot level	104·0
West crosscut 250-foot level	165·0
East crosscut 250-foot level	61·0
	880·1

The Gilker or No. 2 shaft has been sunk to a depth of 18 feet, and the Bois or No. 3 shaft to a depth of 64 feet.

The rock at the portal of the 100-foot level consists of shales, in beds of from 2 to 4 inches thick striking north 75 degrees west and dipping 55 degrees southwest. The rock is finely jointed and traversed by small quartz stringers along the jointing and bedding planes. About 75 feet from the portal a breccia zone 12 feet wide contains a network of stringers with some masses of yellow zinc blende. From this point to within 20 feet of the south drift, the shales are poor. This last 20 feet, however, consists of breccia with some sphalerite.

The south drift follows a vein the foot-wall of which is sharply defined but whose eastern border fades out into brecciated shale. The vein as exposed here is from 5 to 8 feet wide and consists of quartz and carbonate with sphalerite and galena, and numerous small horses of shale with a part of the vein in the foot-wall. The foot-wall follows a post-mineralization fault plane marked by a zone of crushed shale which varies up to 6 inches in width. The short south crosscut exposes heavily-bedded dark shales. A little ore is exposed at one place in the face, but there is no definite vein. Two parallel light-coloured zones of soft material, ½ to 6 inches in width, which follow the bedding planes and which are evidently minor shear zones, occur in this crosscut.

The drift, north of its junction with the adit, cuts through vein and mineralized breccia material (Plate V). In places the vein carries a series of parallel bands of amethystine quartz showing a succession of reopenings and closings. A large horse of shale 10 feet long and 2½ feet high is present in the mineral zone. Immediately south of the shaft the vein is from 12 to 16 feet wide.

At the north crosscut the fault plane which borders the south drift is well marked; 1½ feet to the west of it another fault is seen parallel to it. At 65 feet along the

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crosscut is still a third fault which runs at right angles to the crosscut. The north crosscut traverses shale in beds from 1 to 6 inches in thickness and contains a few stringers of vein material. A short drift from the north crosscut follows a vein 5 feet to 6 feet wide which is probably the underground extension of No. 3 vein, and carries high percentages of ore.

North of the shaft the main drift follows the Federal vein which here shows quartz and ore up to 12 feet in width bordered by a zone of mineralized breccia. At 180 feet north of north crosscut No. 1 the vein is cut off by a fault plane dipping at an angle of 50 degrees to the east. The fault plane is an open fissure and strikes north 45 degrees west.

North of this fault the north drift follows a vein known as the porphyry from the fact that it parallels a band of light-coloured rock, though throughout its exposed length there is a band of black shale 1 to 3 feet wide between the vein and the light grey rock. This rock, which is approximately 50 per cent carbonate, is apparently a porphyry intrusion, highly altered by carbonated solutions. In places it contains disseminated masses of zinc blende. The vein has a width of from 1½ to 6 feet, is bordered by breccia, and has been followed for 200 feet. It contains rich zinc and lead values. South of the turn in the drift, the vein disappears, but, 35 feet east of the bend, a vein 3 feet wide—a continuation of the Porphyry vein—crosses the drift. From here to the breast of the drift the walls show nothing but shale striking north 67 degrees east and dipping 27 degrees southeast.

North crosscut No. 2 is driven through shales and dense, dark-coloured crinoidal limestone for 55 feet and then passes into porphyritic syenite. This rock is fresh and massive, but shows local slickensided fractures and small quartz stringers. North crosscut No. 3 exposes only shales.

On the 250-foot level, a total length of 226 feet of crosscutting has been done. East of the shaft the rocks exposed consist of shales and limestones. These rocks are interbedded, but in places irregular masses of limestone are surrounded by shale—a condition brought about by the deformation of the beds. Near the east end of the crosscut some rich ore has been exposed. On the north side is a vein zone 4 to 5 feet wide containing zinc blende and galena in large masses and bordered by a broad breccia zone. Directly opposite, on the south side, is a rich zone 12 feet wide. A fault plane appears on the roof of the crosscut on the north face and cuts the south face about 2 feet above the floor of the crosscut. The fault is parallel to the bedding of the shales. Either two veins have been brought together at this point or there has been faulting across a vein bringing a wider part over a narrower part. The fault plane shows a marked gouge zone and slickensided striations.

West of the shaft the crosscut shows a number of features of interest. Ten feet from the shaft is a brecciated vein zone containing ore. Fifteen feet farther on is a fault plane dipping 20 degrees to the east which is open in places and forms a water course. Several other faults are exposed in this crosscut and a few small veins with accompanying breccia zones. Numerous veinlets of pale pink calcite here cut the shales.

Ore Values. The veins exposed throughout the workings show good values in zinc and lead ore, and even the brecciated zones are in places rich enough to be mined. The following is a list of assays from samples cut across the quartz veins at various points and across some of the brecciated zones. The samples were taken by Dr. Walter Harvey Weed and are given here through the courtesy of the Federal Zinc and Lead Company.

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Samples

No.	Location	Thickness	Lead	Zinc
		Feet	%	%
1	Between tunnel and south drift	12		
2	Quarts-spar vein next to wall opposite south drift	8·4	2·8	8·2
3	Breccia, east of No. 2	9·5	0·0	1·0
4	Across vein north end south drift	6·3	3·1	11·1
5	South face, end south drift	6·5	14·1	5·8
6	Vein at 61 feet south of inclined shaft, foot-wall	6·0	6·6	4·4
7	Vein at 61 feet south of inclined shaft, hanging-wall	5·4	3·4	3·9
8	Point 20 feet north of No. 7, 41 feet from shaft, hanging-wall	6·0	0·9	3·6
9	Point 20 feet north of No. 7, 41 feet from shaft, hanging-wall	6·0	0·9	6·8
10	At first crosscut northwest of shaft	8·2	1·5	3·2
11	30 feet north of No. 10	6·0	2·5	15·3
12	22 feet north of No. 11	6·0	3·0	8·3
13	30 feet north of No. 12	4·8	2·2	8·4
14	16·2 feet south of Survey Hub No. 8, 20 feet north of 13	3·5	9·5	15·3
15	12 feet north of Survey Hub No. 8	6·0	9·2	8·3
16	46 feet north of Hub No. 8	6·0	1·2	5·7
17	Crosscut to east breccia at end of east crosscut	10·0	0·0	3·9
18	Breccia west of 17	10·0	0·0	trace
19	Across vein over porphyry in crosscut west for 10 feet from drift	7·5	0·0	3·3
20	Breccia corner of east crosscut north side next to drift and to No. 18	4·3	0·0	1·1
21	35 feet from east crosscut	4·0	0·2	2·7
22	12·6 feet beyond No. 21 opposite fault	10·0	2·3	8·2

"A composite sample representing equal parts of material from twelve cuts across the Federal vein from the extreme south end to the northernmost point exposed shows 3·8 per cent lead and 7·9 per cent zinc with 9·46 per cent lime and 43·85 per cent silica. This composite sample is considered as representative since it checked up closely with the calculated average of the individual assays and it may be accepted as an average for the entire vein so far as exposed underground".

The assays show that the lead content of the veins and brecciated zones varies from nothing up to 14 per cent and the zinc up to 15 per cent.

Conclusion Regarding Deposits. The development which has been carried out so far indicates that there is a large quantity of ore in sight. With regard to the persistence of the veins in depth, vein outcrops have been found throughout a vertical range of 560 feet, this being the difference in elevation between a vein exposed in a cut for a road in the valley bottom and that of the outcrops on the summit of Federal hill. It is probable that such strong veins as the Federal, the Porphyry, the McKinlay, and others extend to much deeper than this. It is commonly assumed that a vein is as deep as it is long; hence, a depth of 1,000 feet or even considerably more is quite to be expected. Should this prove to be the case the Federal would have an available tonnage that would make this one of the large zinc properties of America. The ore is of excellent quality, is in no way complex, and should be easy of concentration. The handicap at present to further development is lack of good means of communication.

OTHER PROSPECTS

The North America Mining Company holds the mining rights on claim $\overline{L}$ and several other claims of the area. On claim $\overline{L}$ a shaft has been sunk 30 feet and two open-cuts have been made. The veins opened up are similar in character and mineralization to those on the Federal Company's holdings, but so little work has been done that it is impossible to make any statement with regard to their possibilities.

The surrounding region deserves to be still further prospected. In addition to the zinc and lead deposits chalcopyrite has been found in several of the veins of the region which suggests the possibility of copper deposits being located. The contacts

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of the Tabletop batholith with the Palæozoic sediments should also be searched for ore deposits. The serpentine belt likewise deserves to be thoroughly prospected. Chromite is known to be present in small quantities and it is possible that deposits of commercial importance may yet be found. Similar basic rocks in other parts of the world are also the source of platinum.

PETROLEUM

Locally the Gaspe sandstone of the map-area contains small amounts of bituminous material. Whether this series anywhere throughout the peninsula carries sufficient oil to be of commercial importance is a question of considerable economic interest. Present knowledge of the possibilities of oil in Gaspe may be very briefly stated. In order to have an oil field four things from a geological point of view are necessary.

(1) There must be oil in the region.
(2) There must be a favourable structure to give the oil an opportunity to accumulate.
(3) There must be strata of porous rock to serve as a reservoir to contain the oil.
(4) There must be an impervious capping rock over the reservoir to retain the oil.

It may be definitely stated that there is oil in Gaspe. Drilling for oil on York river was carried on for over 40 years and altogether 52 wells have been sunk, some of them to a depth of 3,700 feet. In 1901 and 1902 some 200 barrels of oil were obtained. Even the best of the wells, however, gave only a small daily yield which rapidly fell off to nothing on pumping. Nevertheless the occurrence of oil springs and the finding of oil in the wells even though only in small quantities shows that the peninsula does contain petroleum.

With regard to structure, the Palæozoic rocks of Gaspe are thrown into anticlines and synclines and at the eastern end of the peninsula the major structural features are known. Besides being folded, however, the rocks have also been faulted. The conclusions of Ells from his studies in this field was that faulting was so extensive that the oil had escaped along fissures instead of becoming concentrated in any reservoir. Very little, however, is known of the structure of the interior of the peninsula. The dips of the Gaspe sandstone are known in many places to be low and it is quite possible that there may be areas where there has been but little faulting and where the folding is sufficiently gentle to make favourable places for oil accumulation.

With regard to the third condition, that of a reservoir for the oil, the Gaspe sandstone itself is admirably suited for this purpose. If the series is continental there is very little chance of the series itself being an original source of oil except perhaps in some of the basal beds which are known to contain a marine fauna. Underlying the series, however, are the Gaspe limestones and older Palæozoic rocks of marine origin which may be a source of oil which might accumulate at favourably situated places in the Gaspe sandstone above.

The question of a capping rock is one to which a less satisfactory answer can be given. Shale occurs throughout the Gaspe series, but not in definite, widespread horizons such as are found in a marine series. Where it does occur, it is in local irregular beds which pinch out rapidly laterally. The question of a good cover would, therefore, seem to be the chief difficulty in the way of oil accumulation in the peninsula. A possible substitute for an impervious shale capping rock might possibly be found in the basic lava flows of the peninsula. As already mentioned, these are widespread in the area mapped. It might possibly be found that at some place of favourable structure they are of sufficent areal extent to serve as an efficient capping to an oil reservoir. A great deal of careful areal geological work would be necessary, however, before recommendations for drilling could be dependably made. The presence of igneous rocks interstratified with and cutting the sedimentaries is, on the other hand, not usually regarded as a condition favouring the existence and accumulation of petroleum.

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SUMMARY

The zinc and lead deposits which have led to a new interest being taken in the economic possibilities of Gaspe peninsula are situated near the headwaters of the north branch of Berry Mountain brook, a tributary of Cascapedia river. They are reached by a wagon road from Cascapedia station on the Quebec Oriental railway which follows along Chaleur bay. This road follows Cascapedia river and Berry Mountain brook and from the railway to the Federal zinc and lead property is a distance of 46 miles. A great deal of work has been done on this road, but in order to put it in condition for efficient summer transportation much still remains to be done.

TOPOGRAPHY

The central part of Gaspe peninsula is a plateau with an approximate elevation of 1,800 feet. To the north lie the Shickshock mountains which reach elevations of over 4,000 feet. The upland topography is characterized by mature slopes; the interfluvial areas are as a rule flat. The valleys, however, which are deep and steep-sided, have evidently been produced by stream cutting following the uplift of a maturely-developed topography.

The region was apparently not overrun by the Pleistocene continental ice-sheets. Local glaciers were, however, present in the higher central part of the peninsula, and spread out in all directions, producing cirques and local changes in drainage, and transporting morainic material.

GENERAL GEOLOGY

The oldest rocks are shales and limestones of Lower Devonian age. These rocks are folded, faulted, and intruded by both dyke and deep-seated rocks. Overlying the shales and limestones is a sandstone formation, corresponding to the Gaspe sandstone of the coast sections. In this area it lies flat and contains plant remains. Flows of basic volcanic rocks are associated with the sandstone and cover the greater part of the map-area. Acid lava flows are in places associated with the basic flows. Many varieties of porphyry occur in the region. The plutonic rocks consist of syenite and granite, the syenite occurring as dykes and small stocks, the granite as a batholith which cuts across the structure of the folded Palæozoic rocks. The folding and intrusions took place, probably, in Middle Devonian times, since when the history of the region has been largely one of erosion.

ECONOMIC GEOLOGY

The ore deposits consist of sphalerite and galena in veins which cut the shales and limestone. In places the veins have sharply defined walls, in places they fade out into brecciated zones. The gangue is quartz and dolomite; some of the quartz is of the amethystine variety. The sphalerite is mostly light yellow and almost free from iron. The proportion of sphalerite to galena is about two to one. Pyrite, marcasite, and chalcopyrite are present, but in only very small amounts. The deposits are considered to be genetically related to the deep-seated acid intrusives of the region.

A large number of veins have been exposed by surface trenching. From No. 1 shaft, on the Federal or No. 1 vein, a considerable amount of development has been carried out. From the 100-foot level, 1,126 feet have been drifted and 776 feet have been crosscut. From the lowest level—257 feet—over 200 feet of crosscuts have been driven. The workings have opened up a large amount of ore, and the prospect for a large tonnage is very favourable.

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POSSIBILITIES OF FINDING OIL OR NATURAL GAS AT EDMUNDSTON, NEW BRUNSWICK

By W. S. McCann

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INTRODUCTION

The following report contains the results of an investigation of reported occurrences of gas and oil at Edmundston, N.B. The work was greatly facilitated by the co-operation of Mr. Alec. Dunbar, who kindly furnished the writer with all available information.

GENERAL GEOLOGY

The rocks exposed near Edmundston are grey calcareous slates, with occasional thin beds of sandstone and quartzite of Silurian age. They have been extremely metamorphosed and are closely folded and faulted. A slaty cleavage, which is usually vertical, obscures in many places the original structural features of the rocks. In recent cuttings for the railway grade, bridge abutments, etc., however, the bedding planes are exposed well enough to permit of the determination of the attitude of the strata.

Evidence of close folding may be seen at the railway bridge at the mouth of Madawaska river, one mile east of Edmundston, and at the site of the new water tank on the northwestern corner of the town. At these points local synclines occur. Faults are of frequent occurrence, and add to the general complexity of the geological structure of the rocks.

ECONOMIC GEOLOGY

The reported indications of gas and oil are as follows:

	Explanation
Pump house. Fraser Co., Ltd., Madawaska river. Bubbles of gas rose to the surface of the water upon agitation of the bottom. The gas was accompanied by oil which spread over the surface of the water as an iridescent film.	Methane (marsh gas) accompanied by certain fatty acids or sulphite turpentine (cymene), which forms a film on the surface of the water.
Madawaska river behind the Madawaska Inn. Bubbles of gas continually rising to the surface of the water at various points, more or less in alignment nearly across the river. Small amount of oil accompanies the gas, which latter burns readily, if collected in a container.	Methane and oily substances noted above.
Drilled well at site of old Block House, east side of Madawaska river. Two wells were drilled at this point several years ago ostensibly for oil. It is alleged that the water from these wells was oily, and of disagreeable odour.	Stagnant water covered with film of iron oxide, from metal off the drill or from iron sulphides present in small quantities in the slates.
Other wells in the neighbourhood are reported to have been disused because of peculiar taste and odour.	
Madawaska river above sulphite-pulp mill. Upon agitation of bottom large bubbles of gas rose to the surface. This gas was *not* accompanied by oil.	Methane. Absence of material probably because of absence of waste products of pulp mill at this point.

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Air-free samples of the gas were collected at various points, together with samples of the river water and water from the bored well at the site of the old Block House. These samples upon analysis by R. T. Elworthy of the Mines Branch yielded the following results:

Analysis of Gas Samples

——	I	II	III	IV
Carbon dioxide (CO_2)	2·8	1·8	1·1	None
Oxygen (O_2)	2·3	2·8	3·1	None
Methane (marsh gas) (CH_4)	91·4	71·5	67·4	80·0
Nitrogen (N_2)	3·5	23·0	28·4	12·8
Ethane (C_2H_6)	None	None	None	7·2
Density compared to air	0·615	0·685	0·698	

I. Sample collected at boiler house, Fraser Co., Ltd.
II. Sample collected 200 yards from west bank Madawaska river in rear of Madawaska Inn.
III. Sample collected in midstream Madawaska river in rear of Inn.
IV. Sample of natural gas, Moncton, N.B., included for comparison.

The analyses of the gas show that it is largely methane or marsh gas (CH_4). The gas shows no trace of higher hydrocarbons such as ethane and propane which are usually found in natural gas. The small amounts of oxygen compared with the amounts of nitrogen in II and III are accounted for by the increased solubility of oxygen in cold water. (Oxygen is about 2·5 times more soluble than nitrogen.)

The gas, at the time of collecting, smelled strongly of hydrogen sulphide (H_2S), but the analyses do not indicate its presence, perhaps because some water was left in the jars in which the gas samples were collected, and the H_2S was dissolved by it. Some CO_2, also, was probably dissolved in the same way.

Analyses of Water Samples

A sample of water from Madawaska river below the sulphite-pulp mill was found to contain 75 parts of mineral matter per million parts of water. This mineral matter was composed of calcium sulphate and sodium chloride, and the water was slightly alkaline in reaction.

Water collected at the bored well at the site of the old Block House contained 673 parts per million mineral matter composed of calcium and manganese bicarbonates and sulphates, sodium chloride, and traces of iron hydroxide, the latter forming a film on the surface of the water.

No trace of oil was detected in either sample.

PROBABLE EXPLANATION OF THE PRESENCE OF OILY SUBSTANCE

Accompanying the gas bubbles in the river below the sulphite-pulp mill there are small amounts of an oily liquid which forms an iridescent film on the surface of the water. It occurs in such small amount that it was impossible to collect enough for testing or analysis. In the river above the sulphite-pulp mill, the marsh gas which rose to the surface of the water upon agitation of the river bottom was not accompanied by an oily substance. This fact points toward the waste products of the pulp mill as a possible cause of the continuous bubbling of gas and the presence of the oily liquid.

Madawaska river below the place where the gas occurs is dammed, so that there is little current. In former years there was a sawmill on the east bank of the river, but it is possible that most of the sawdust was swept out into St. John river. Some

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of it, however, may have lodged in places where eddies occurred. It is known that the decomposition of sawdust at the bottom of rivers, even of swift current, produces marsh gas in sufficient volume sometimes to break the ice covering it in winter. It is not certain, though, that the gas observed has resulted from sawdust, and another explanation must be sought.

Now, mangled bark, resins, and gums in large quantities are being discharged into the river along with other waste products of the pulp mill, including so-called sulphite turpentine, a compound largely composed of cymene, which is an oily substance. Also, in the decomposition of the cellulose of the organic materials at the bottom of the river certain fatty acids (butyric acid, valeric acid, etc.) of molecular weight less than that of cellulose, are produced. Such substances would rise to the surface and spread over the water as an oily film. In this way the oily substance may be accounted for.

ABSENCE OF OIL OR GAS IN NORTHERN MAINE

The reported discoveries of oil or gas in Maine have been found to be without foundation. Mr. Freeman F. Burr[1] states:

"The search for oil in this state (Maine) is probably fully as hopeless as that for coal. . . . Oily material in small quantities may occasionally appear in connexion with surface deposits, since such material is a product of animal and plant bodies: but the chances are almost overwhelming against the finding of oil in the underlying rocks, chiefly because these show abundance of evidence of having been folded and fractured to such an extent that any volatile materials would inevitably have been expelled into the atmosphere long ago. It seems best to discourage any expectation of oil anywhere in Maine."

The reported discovery of oil near Dover on the Piscataquis river is not endorsed by the Maine Water Power Commission.[2] Samples of the supposed oil, which were sent to the University of Maine for analysis, were reported to be refined oil.

CONCLUSIONS

The rocks of the district are extremely metamorphosed, highly folded and faulted, and are not, therefore, favourable for the retention of oil or gas.

The gas which occurs is marsh gas (methane) and has resulted from the decomposition of organic materials at the bottom of the river.

The oily substance which spreads over the surface of the water in small amounts is probably cymene (sulphite turpentine) or certain of the fatty acids resulting from the decomposition of organic materials on the river bottom.

[1] Geologist, Main Water Power Comm., 1st Ann. Rept. M. W. P. Comm., 1920, p. 116.
[2] Personal communication.

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PLATE I

Uraninite-bearing dyke of segregated type—McQuire-Robertson claims. Lots 9 and 10, concession IX, Conger township, Parry Sound district. (Page 61.)

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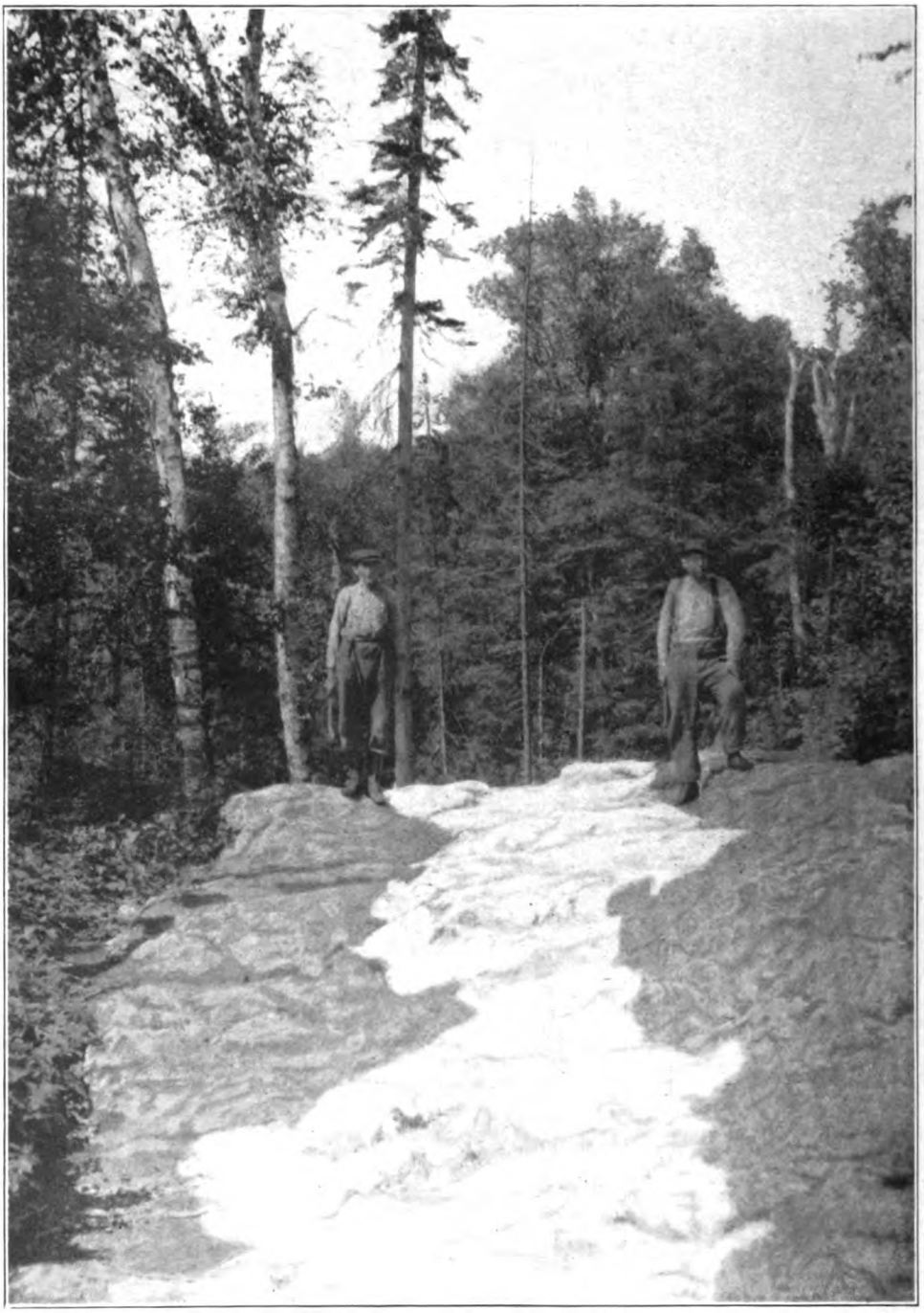
PLATE II



Segregated veinlike dyke—white quartz in middle, feldspar at sides. Ryan, Mann, Sheehan claims, lot 3, concession VI, Butt township, Ont. (Page 56.)

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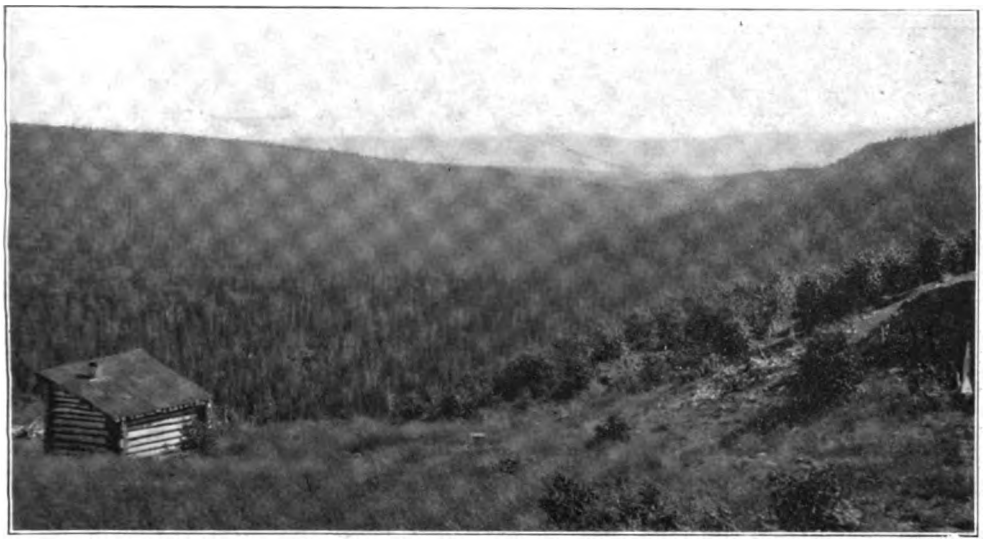
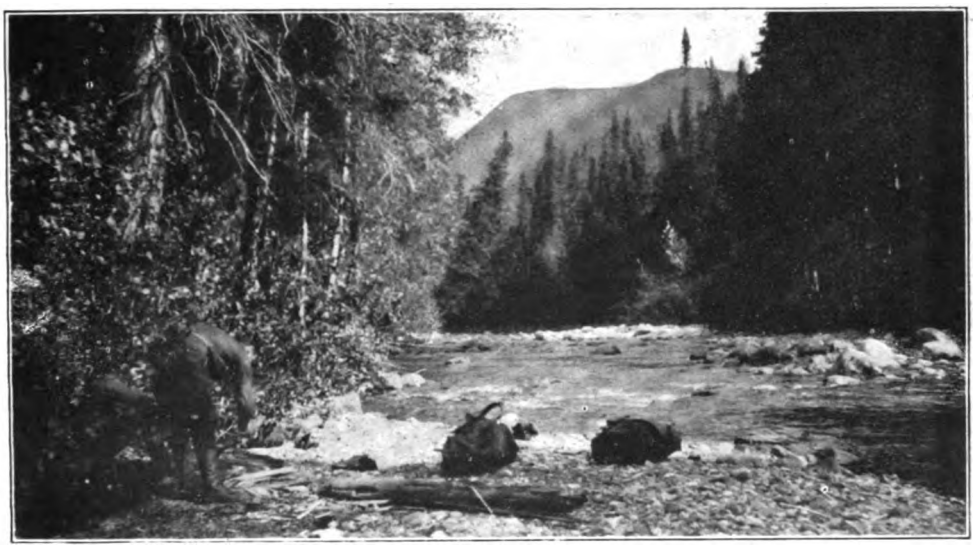
PLATE III



A. View down Berry Mountain brook from the Federal mine, showing the plateau surface. (Page 76.)



B. Ste. Anne river below Ste. Anne lake, showing the youthful character of the valley. (Page 76.)

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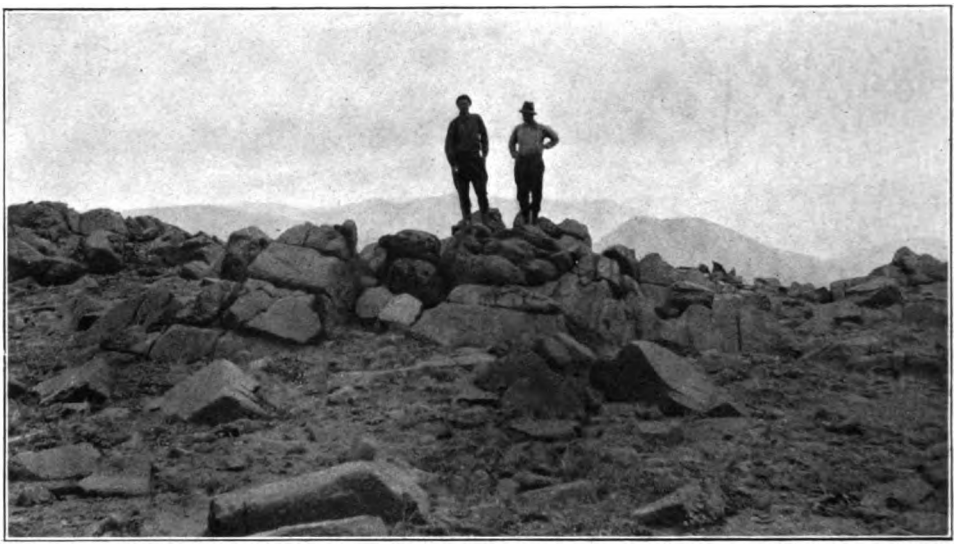
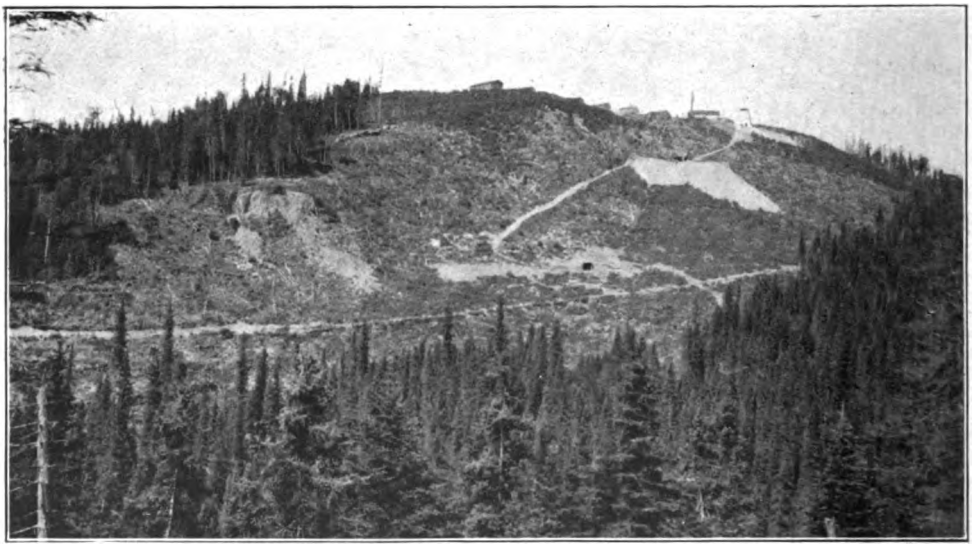
PLATE IV



A. View on the top of mount Albert, showing the unglaciated surface. (Page 78.)



B. Federal Zinc and Lead mine from across Berry Mountain brook. (Page 90.)

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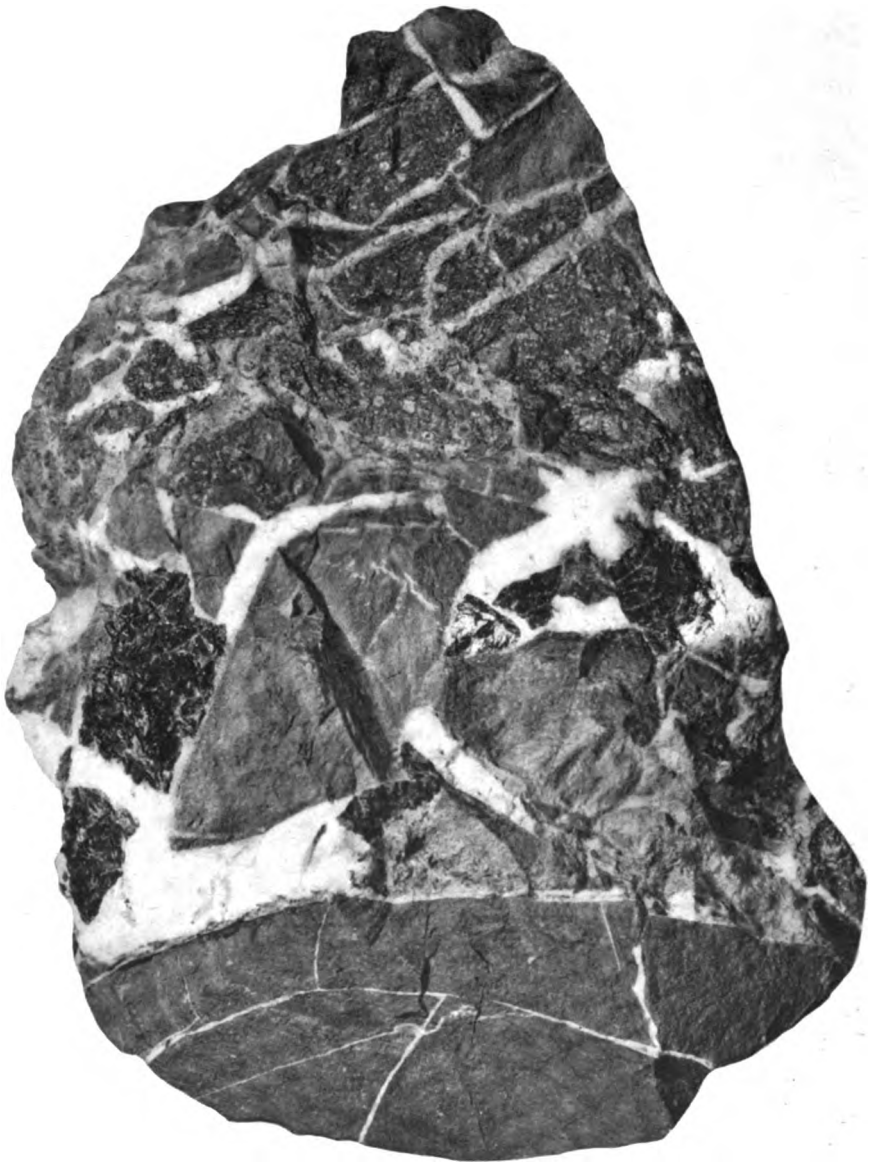
PLATE V



Brecciated shales and limestones, mineralized with sphalerite and quartz. Approximately natural size. (Page 92.)

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[1]NOTE. All localities unless otherwise designated are in Ontario.

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CANADA
DEPARTMENT OF MINES
HON. CHARLES STEWART, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER
GEOLOGICAL SURVEY
W. H. COLLINS, DIRECTOR

Summary Report, 1921, Part E

IRON-BEARING ROCKS OF BELCHER ISLANDS, HUDSON BAY

BY

G. A. YOUNG

OTTAWA
F. A. ACLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1922

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SUMMARY REPORT, 1921, PART E

IRON-BEARING ROCKS OF BELCHER ISLANDS, HUDSON BAY

By G. A. Young

CHAPTER I

INTRODUCTION

Purpose and Character of the Report

This report presents information obtained from an examination of a Precambrian "iron-formation" occurring on Belcher islands, Hudson bay. The field work was done during the summer of 1921 in an interval of about four weeks, too short a period of time to permit of investigating more than the eastern part of the islands. The first part of the report contains an account of the general geology of the islands together with a detailed description of the iron-formation and has been prepared for readers familiar with the principles of geology. The concluding section of the report reals with the possible economic value of the iron-bearing horizon and is written in the hope that the discussion may be serviceable to readers interested in iron ore occurrences but perhaps unversed in geology.

Location and Area

Belcher islands lie off the eastern coast of Hudson bay, 70 miles due north of cape Jones, which marks the division between Hudson bay and James bay. Their southern extremity is 55 miles west-northwest of the mouth of Great Whale river, the nearest locality on the mainland. The island group is 70 miles long, north and south, and about 45 miles broad, but much of the area is occupied by water. The chief islands are separated by broad seaways and are either narrow, or where broader, are deeply penetrated by bays and inlets. A large part of the main island of the group is occupied by a lake reputed to be 40 miles long.

Transportation

Belcher islands may be reached in winter over the ice or in summer by boat. The Hudson's Bay Company and Revillon Frères maintain power-driven vessels on James bay. These boats make one or more trips a year from Moose Factory north along the east coast of Hudson bay, but normally these vessels are not available for transportation to the islands. Small sailing craft may be hired or purchased from these fur-trading companies, but it is questionable if crews to man them could be procured on James or Hudson bay. At present, 1921, two small decked-in power boats belonging to the Belcher's Islands Iron Mines, Limited, are the only other available craft known to the writer. Boats of size and sea-going qualities sufficient for the trip to the islands can be taken with little trouble to James bay from the Canadian Government railway crossing of the Pagwachuan branch of Albany river. Advantage should be taken of

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highwater conditions in the spring of the year; when there is for a short time ample water from the railway to the bay for the transport, without portages, of small cruising power boats. From the mouth of Albany river, the usual route is across James bay via Charlton island and northerly along the east coast to the north end of Long island, north of cape Jones. From there a course about

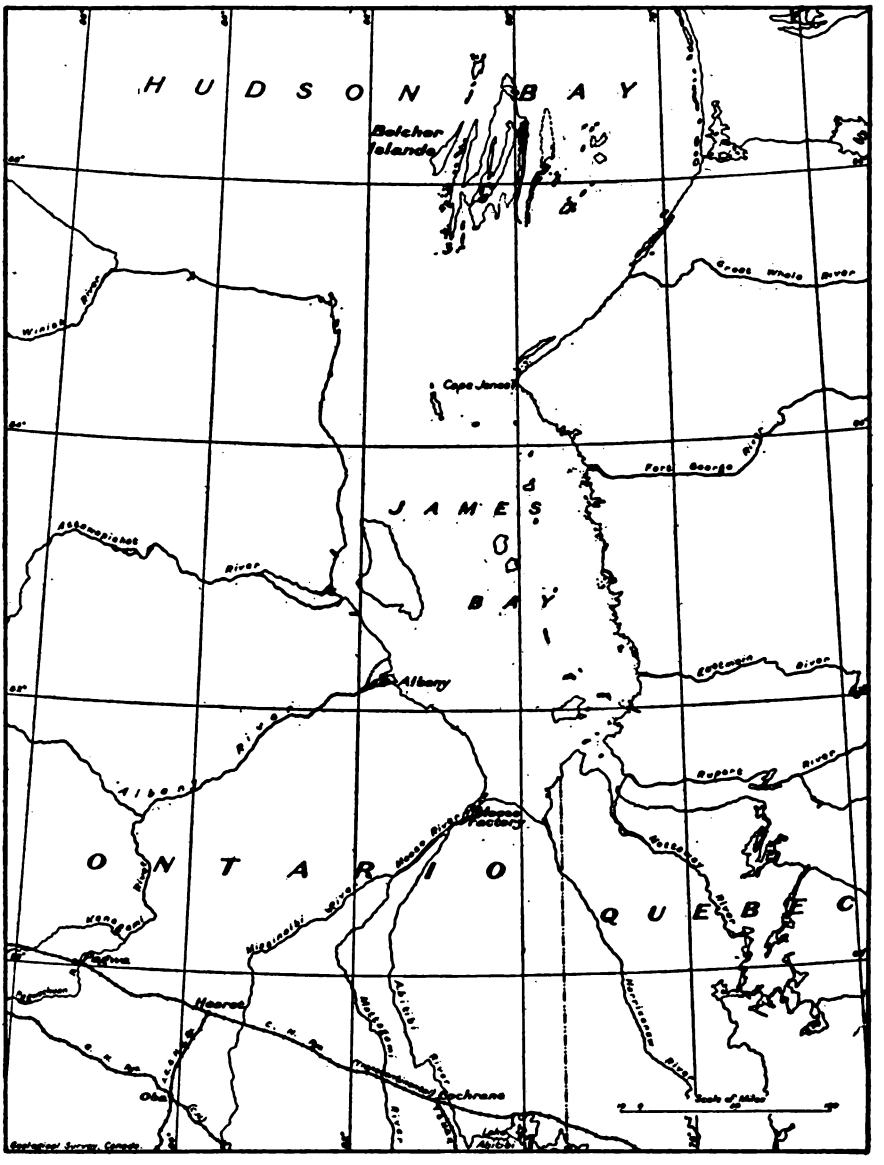

Figure 1. Index map showing location of Belcher islands, Hudson bay.

20 degrees west of true north will reach the southeast part of the islands. The period of navigation for small craft varies from season to season. As a general rule, about the middle of June is reasonably early for starting from Albany river. The return trip may be made in October or a little later.

Navigation to and from Belcher islands by large ocean-going vessels should not be attended with any great difficulty if the uncharted region north and north-

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east of the islands is avoided. The approach in other directions is free of islands or shoals. At many places on the islands secure harbours for the largest vessels are available and, should mining operations ever be carried out, docking facilities reasonably close to the mines could be provided without much difficulty. On the other hand a careful charting of the seaways seems to be a preliminary and imperative necessity, since in several of the sounds isolated reefs were noted barely awash at low tide, and the clusters of small islands bordering the main group suggest that shoal reefs may be present there also.

Previous Accounts

Belcher islands have long been known to form the southernmost group of a chain of islands lying off the east coast of Hudson bay and extending northwards for several hundred miles. Though inhabited by Eskimos, who each winter cross the ice to trade at the Hudson's Bay Company's posts, and although about the middle of the last century an official of this company visited the islands, yet in spite of these facts the position, extent, and general character of Belcher islands were until recently conjectural. Modern maps represented them as formless clusters of dots. In 1914, 1915, and 1916 the islands were visited by R. J. Flaherty, then engaged in exploratory work on behalf of Sir William Mackenzie, and in 1918 Flaherty published a map and an account of the islands in which he drew attention to the possible value of the iron-bearing strata.[1]

E. S. Moore, in 1916, visited the islands in the interests of Sir William Mackenzie and later published several accounts dealing with the general geology and the nature and possible economic value of the iron-formation.[2] Mr. Moore has described the islands as being formed of a thick assemblage of sedimentary strata, intruded by diabase sills, resting on a mass of basalt and diabase and capped by flows of basalt. He named the sedimentary group the Belcher series and concluded that it is of Precambrian age. It was found to be folded into long, broad, pitching anticlines and synclines. The uppermost member of the sedimentary series, which he named the Keepalloo (Kipalu) formation, was determined to be an iron-formation, with a variable thickness of several hundred feet, that everywhere lies immediately beneath the basalt flows. This iron-formation "consists of jasper, chert, hematite, magnetite, siderite, and green granules regarded as the iron silicate, greenalite" and Moore suggested that "algæ and iron bacteria have been responsible for the precipitation of colloidal silica, hematite, and iron silicate in . . . granular form, in some places as a direct precipitate . . . in others as a replacement of . . . calcite granules by the iron compounds."

Regarding the possible economic importance of the iron-formation, he wrote that "the wide distribution of the iron-formation and its location on hillsides and on the flanks of synclines combine to produce conditions so favourable for the concentration of ore-bodies that it is surprising that important bodies do not occur . . . The greater part of the formation is, however, very lean siliceous material . . . [and] while there are bands of low-grade ore in the iron-formation the great bulk . . . is lean and siliceous . . . [and]

---

[1]Flaherty, R. J., "The Belcher Islands of Hudson Bay; Their Discovery and Exploration," Geog. Review, vol. 5, No. 6, pp. 433-458, 1918.

[2]Moore, E. S., "The Iron-formation on Belcher Islands, Hudson Bay, with Special Reference to Its Origin and Its Associated Algal Limestone," Jour. of Geol., vol. 26, pp. 412-438, 1918.

"Iron-formation on Belcher Islands, Hudson Bay, with Special Reference to Its Origin and Its Associated Algal Limestone," Bull. of the Geol. Soc. of Am., vol. 29, p. 90 (abstract only), 1918.

"Iron Deposits on the Belcher Islands, Hudson Bay," Monthly Bull. of the Can. Min. Inst., No. 82, Feb., 1919, pp. 196-206, 1919.

"Ore Deposits of Arctic Canada," Eng. and Min. Jour., vol. 110, pp. 396-400, 1920.

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along the strike these bands of ore finger out into the jasper." Mr. Moore has distinctly stated that considering the character of the iron-formation and the climatic conditions and geographical position of the islands, the iron-formation is not of present economic value.

Other parties than those represented by Messrs. Flaherty and Moore became interested in the possibilities of the iron-formation. Expeditions were sent to the region, and the staking of claims commenced in the year 1916. As a result of these operations, twenty-two claims have been located and leases for them granted under the provisions of the regulations governing iron-ore locations in territories subject to the direct jurisdiction of the Federal Government. Twenty of the claims are of square outline, each enclosing approximately 160 acres. Two claims are each less than 25 acres in extent. These claims are controlled by the Belcher's Islands Iron Mines, Limited, Toronto. This company has twice sent engineers to the islands to report on the value of their claims. One of these, Mr. Dwight E. Woodbridge, has expressed the view that "extensive areas were found in the formation where there had been sufficient concentration of ore to present faces up to 25 feet in thickness of an average iron content of better than 52 per cent natural iron. . . But not enough commercial ore was disclosed by my examination to permit a recommendation that the development of mines, the construction of ships, docks, and a railway were warranted without further and considerable definite knowledge . . . [although] it was reasonably safe to assume the actual presence of commercial ore in mineable thicknesses up to a tonnage not far from a million tons."[1] Mr. Woodbridge has stated as his opinion that the existence of commercial tonnages of iron ore depended on, firstly, whether structural and other conditions were such as to permit of ore-bodies forming if the necessary solvents could act, and, secondly, whether the iron-bearing rocks now covered by diabase sheets were ever "exposed to atmospheric action for a sufficient period to permit . . . concentration to proceed adequately to make ore." He gave reasons for his belief, firstly, that structural conditions were such as to favour the concentration of the iron in ore-bodies, and, secondly, that the overlying lavas were much younger than the iron-formation and, therefore, that the iron-bearing strata had remained uncovered for a long period during which conditions favoured concentration of the iron content.

General Character of Belcher Islands

The general outline and size of the Belcher group are indicated in Figure 2. This sketch, compiled by members of the various private expeditions sent to the islands, is sufficiently accurate for general purposes, although it is erroneous in many respects both as regards major and minor features. Shapes and relative dimensions are all subject to revision. Many smaller islands and other minor features are not indicated and, on the other hand, major features shown in the sketch may be non-existent or wrongly located.

From the east side of Belcher islands, a number of islands are visible, some quite small, others several miles in length, and it is reported that if a course is followed eastward from the northern part of the islands to the mainland, land is in sight at all times. A number of small islands lie along the south and west sides of the Belcher group, but to seaward beyond these, both to the south and west, is open water free of islands. Northward, at varying intervals, groups of islands extend for several hundred miles.

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[1]Woodbridge, D. E., "Iron-ore Deposits on Belcher Islands," Eng. and Min. Jour., vol. 112, pp. 251-254, 1921.

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The islands of the Belcher group are in general elongated north and south. Their outline and relief are, in the main, directly dependent upon the geological structure and character of the strata. The measures lie in broad folds that strike north and south. Erosion has been most vigorous along the arches of these folds, where it has removed a once continuous cover of basaltic sheets and produced long depressions that form long arms of the sea or valleys. One of these is partly occupied by the 40-mile long lake on Flaherty island. The limbs of the folds, still capped by the basalt sheets, form long, steep-sided ridges. The

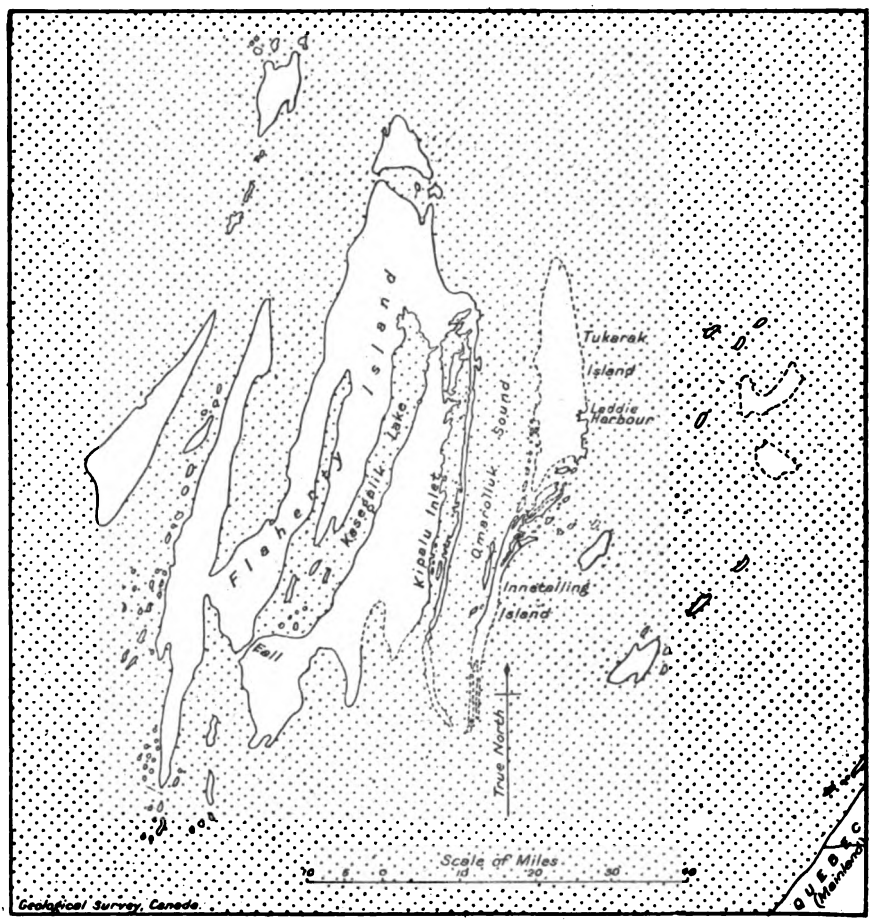

Figure 2. Sketch map of Belcher islands, Hudson bay.

synclinal portions, still preserving the capping of diabase, either underlie sounds or form steep-sided, broken uplands. There is a general southerly dip of the strata which has resulted in a gradual decline from north to south in the heights of the elevated portions which probably nowhere reach 400 feet above sea-level and in general are less than 300 feet high.

The main low-lying areas are variable in character, because of variations in the geological structure and the character of the bedrock, the local presence of diabase sills, and, along the anticlinal axes, the existence of large bodies of diabase. Thus the valleys show nearly level areas where the strata underneath are approximately horizontal; or long, rolling ridges corresponding to gentle folds in the measures; or occasional abruptly rising hills due to structural features or to

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the presence of a protective covering of locally developed sills of diabase; and, lastly, broader, more irregular ridges formed of diabase masses occurring along the anticlinal axes. Occasional comparatively narrow valleys cross the main ridges and join one major low-lying area with another. These cross-valleys are prominent local features which may be in part due to glacial action.

The main upland areas formed of the capping diabase sheets rise steeply, and in places precipitously. On top their surface is in general level but broken by step-like rises and drops from the surface of one sheet to another. They are almost bare of soil. Talus material occurs along the steeper slopes; the lower part of these slopes, the sides of the minor ridges and hills, and the floors of the depressions are mostly largely mantled with moss-covered sandy deposits. The islands are bare of trees. Alders grow only in open clumps of small, stunted individuals and the plant life in general is sub-arctic in character.

The physical features of the main islands lying east of Omarolluk sound (Figure 2) follow a simple general plan. These islands are traversed from north to south by an anticlinal axis whose course is marked by a low-lying area. In the south the continuation of the anticlinal axis is marked by a channel between two long, slender islands tipped by islets. Each island is composed of sheets of diabase dipping away from the intervening channel and rising steeply from the sea to a comparatively level top whose general elevation increases northward. This same structure is continued northward on Innetalling island, but there the anticlinal portion soon emerges from the sea and forms a long valley a half mile or less broad, but widening at the north end. The floor of the valley where it is narrow is heavily drift covered. Northward where the valley broadens, its character is more variable and at the north end of the island it is partly occupied by abruptly rising rocky ridges. The continuous, bounding diabase ridges are only from a quarter of a mile to somewhat over one mile wide.

The above general structure continues northward into Tukarak island, but there the western diabase wall is confined to a line of fringing islands which extend northward for a few miles only. On the east side, the comparatively narrow diabase ridge continues, so far as known, for the whole length of the island, but is broken through by several cross-depressions, two of which are bays of the sea. West of the eastern diabase ridge rises a second but lower line of broken ridges bounded on the west by a rolling area in part swampy and only a few feet above sea-level. Still farther west, in the south of the island, a long, broad ridge marks the position of a large body of diabase disposed along the anticlinal axis. The western side of this ridge slopes gradually seaward to the low shores which are there bordered by the already-mentioned line of islands that represent the partly submerged, northern part of the west diabase ridge.

Omarolluk sound, lying west of the above-described island group, is presumably a synclinal area doubtless floored by the diabase sheets which reappear on the west side and there form a peninsula about 40 miles long and for the most part less than half a mile wide. This peninsula, a part of Flaherty island, is continued southward by a long, narrow, low island which trends to the east of south so as partly to cut off Omarolluk sound on the south.

The above-mentioned peninsula and the island continuing it to the south separate Omarolluk sound from Kipalu inlet, lying to the west. Kipalu inlet lies along an anticlinal axis; it is about 50 miles long by 2 to 3 miles broad, open at the south end but closed at the north by a narrow strip of land forming part of the northeast coast of Flaherty island. On both sides rise steep-sided ridges that gradually increase in elevation from south to north. These ridges are formed of diabase sheets that dip away on either side from the water, with here and there small promontories and islands of the underlying strata. The ridges are broken, are crossed at infrequent intervals by low, narrow valleys,

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and at the north end nearly coalesce so as almost to encircle the inlet. Towards the north, the diabase ridges are bordered by more continuous low-lying areas and there, towards the centre of the inlet, ridges of diabase rise as islands along the axial portions.

The ridge bordering Kipalu inlet on the west marks the position of a syncline, and the diabase sheets composing this upland are for the most part approximately flat lying. The summit of the ridge is broken by minor depressions, though tending to be flat. The width varies from half a mile or less to 5 or 6 miles in the north, where it forms part of the northeast coast of Flaherty island.

West of this synclinal ridge lies the valley of Kasegalik lake. The lake stands about 25 feet above sea-level and is reputed to be 40 miles long and in places 5 to 10 miles broad. The valley in which it lies continues northward beyond the head of the lake to a bay on the north shore of Flaherty island. This general valley marks an anticline. Its eastern side is formed by the steeply rising edges of the diabase ridges separating the lake from Kipalu inlet. On the west, the country, as viewed from a distance, rises in a series of long, broad ridges which perhaps occupy the western part of Flaherty island.

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CHAPTER II

GENERAL GEOLOGY

General Statement

The strata of the eastern part of Belcher islands are a series of little altered sedimentary rocks capped by sheet-like bodies of diabase; in places, appearing to rest on a basic igneous mass and at various horizons they are cut by sills and dykes of diabase. All these rocks are presumably Precambrian. The sediments are undoubtedly of the same age as those forming the islands which intermittently fringe the east coast of Hudson bay from cape Jones north to Portland promontory, a distance in a straight line of 300 miles. These sediments may be equivalent to the Animikie of the Lake Superior region.

The strata are disposed in broad, parallel folds running north and south. In the east an anticlinal axis extends through the line of islands that commences in the north with Tukarak, a relatively large island, and ends with the small islands 65 miles to the south. Omarolluk sound, which separates this group of islands from Flaherty island, the main island to the west, marks a synclinal axis. Kipalu inlet, west of this, lies along an anticlinal axis whose eastern limb forms a long, narrow peninsula and the long island south of it which, combined, divide the inlet from Omarolluk sound. The ridge bordering Kipalu inlet on the west is part of a synclinal form and the basin of Kasegalik lake, still farther west, marks the position of a succeeding anticline. Very little information regarding the western part of the islands is available, but what is known confirms the assumption that the same general structures and measures continue over that district.

Stratigraphical Section

A geological section across the east limb of the anticline on Tukarak island was carefully measured along a general line about 6 miles long extending westerly from a point south of Laddie harbour. The measurements commenced at the top of the sedimentary series, continued to its base, and were made by running a stadia traverse and carefully observing variations in angle of dip. The strata are for the most part well exposed along the line of section and in general dip eastward at angles which, commencing in the east, diminish from 35 degrees to 12 degrees and then, towards the west, increase to 25 degrees. Structural complexities encountered on the line of section, and the constantly varying angle of dip, detract from the value to be attached to the calculated thickness, but it is confidently believed that the thicknesses assigned to the different horizons are relatively correct and that the total calculated thickness is not far from the actual thickness. E. S. Moore[1] measured a section, presumably in the same general vicinity, and found the sediments to be 9,079 feet thick. The total found by the writer is less than this, as is indicated in the following summary statement in which the horizons are arranged in descending order.

	Feet
Diabase sheets	
1. Iron-formation	365
2. Quartzites with zones of siliceous limestone	1,747
3. Shales and slates, mainly red	723
4. Limestones, variously coloured	2,686
5. Quartzites, with subordinate amounts of limestone and shale	1,646
6. Slates and sandy or tuffaceous beds, etc.	705
Diabase mass	
Total sediments	7,872

[1]Moore, E. S., "The Iron-formation on Belcher Islands," Jour. of Geol., vol. 26, pp. 412-438. 1918.

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The division of the sedimentary series into six members is arbitrary save in the case of the iron-formation, which alone is sharply divided from the underlying strata. Each of the other members grades upwards into the succeeding division by interbedding or by gradual changes in lithological characters. No evidence was found anywhere of a break in the sequence; all the strata appear to belong to one continuous series, for which Moore has proposed the name Belcher series.

Description of Strata

LOWER DIABASE

The lowest member of the general geological section is a mass of diabase prominently displayed towards the west side of Tukarak island. It outcrops there with in places a width of over a mile and extends from the south shore of the islands for perhaps 10 miles northward. This igneous assemblage occurs along the axis of the major anticline of this part of the islands. It is flanked on both sides by the Belcher series which, because of the northward pitch of the fold, passes over and around the northern termination of the igneous body. Southward from Tukarak island, the main fold pitches in the opposite direction, i.e., to the south, and the basic, igneous group is not represented in that direction.

Along the course of the next major anticlinal to the west, towards the head of Kipalu inlet, there is a large island which is chiefly occupied by diabasic rocks bordered on the east side by lower members of the Belcher series. The igneous mass and the sediments thus appear to possess the same mutual relations as on Tukarak island, but in both places the exposures near the contact are poor and it, therefore, may not be affirmed that the igneous rock is older than the overlying sediments. Moore found the same difficulty in attempting to decide upon the relative age of this igneous mass.[1]

The diabase mass on Tukarak island, so far as seen, is composed of rather fine-grained rocks, not sheared nor otherwise materially altered. They do not, apparently, possess ellipsoidal structures nor is there clear evidence of a sheeted form. Approaching the horizon arbitrarily chosen as the top of this member, the rock becomes somewhat finer in grain, and at several exposures is amygdaloidal. The diabase on the large island in Kipalu inlet is coarser grained and is characterized by small irregular areas and streaks that are paler, more coarsely crystalline, and more largely formed of feldspar. Prominent partings in the rock mass divide it into layers 10, 15, and more feet in thickness, and seem to conform in attitude with the structure of the bordering sediments. North of this island, a smaller mass of similar rock occurs along the course of the same anticlinal axis and in this case the sheeted appearance is even more prominent and regular, and certain zones are characterized by well-developed ellipsoidal structure such as is commonly supposed to be characteristic of flows.

DIVISION NO. 6

On Tukarak island, near the line of section, the strata immediately succeeding the diabase mass are very poorly exposed and the lowest division, No. 6 of the measured section, outcrops at only three horizons in a total thickness of 705 feet. The lowest horizon is just above the base of the sedimentary series and is composed of dark, dull reddish, well-bedded argillites and impure limestones. The argillites are faintly banded. They are interleaved with the limestone and also occur within it as thin, discontinuous layers and fragment-like,

[1]Op. cit., p. 418.

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small bodies arranged parallel with one another. The limestone shows, generally, a greenish tinge irregularly developed, is of medium grain, semi-crystalline, and carries numerous round quartz grains.

About 160 feet higher in the series are exposures of diabase grading into amygdaloidal diabase and overlain by a dark grey, faintly greenish, fine-grained, compact rock of very uniform character, though faintly showing a banding marked by variations in shades of colour. At the outcrop of the third and uppermost horizon the beds are dark red argillites banded in various tones. These lie 180 feet below the base of the next succeeding division, No. 5.

Division No. 5

Division No. 5 has a thickness of 1,646 feet and is fairly well exposed along the line of section. The stratum chosen as the base of this division is a purplish red limestone, finely crystalline and traversed by layers and streaks of deeper red, dense argillite. About 10 feet of the limestone is exposed. It is succeeded upwards after a short, exposureless interval, by compact, purple or red argillites, which are interbedded with other rocks. As the series is ascended, the argillites gradually decrease in volume until they are represented by only occasional zones 5 or 10 feet thick.

The greater part of the strata in this 1,600-foot interval are quartzitic. They vary rapidly in texture from bed to bed and alternate with very fine-grained beds which are presumably composed largely of quartz but in many cases have a general resemblance to argillites. The coarser types occasionally hold quartz grains as large as an eighth of an inch across. The beds are a dark greenish grey on fresh surfaces changing to pale grey or pale yellowish on weathered faces. The distinctly sandy types are mainly of small, close-set, glassy quartz grains and the individual beds mostly lack signs of bedding. The finer-grained, almost dense varieties in some cases are massive also, but in other instances they show regularly alternating lines and thin layers of different shades of green and grey. Occasional beds of pale grey, rusty-weathering carbonate occur with the quartzitic measures in the lower part of the division. These are much more abundant in the upper 500 feet, where also the siliceous beds are as a rule paler than below, in some cases pinkish or cream coloured, and in some instances carrying a considerable amount of carbonate.

The carbonate beds occur most abundantly in the upper part of the division and vary in colour from very pale grey to dark grey. They seem to range from nearly pure carbonate to highly siliceous phases. All are very fine grained, usually almost dense. The purer varieties are finely crystalline and on weathered surfaces have a pronounced yellow or deep cream colour. For the most part the carbonate rocks effervesce feebly and are presumably magnesian and in part, perhaps, iron-rich. On weathered surfaces some of them show very fine, regular banding, whereas others are very rough, deeply and irregularly recessed, apparently because of the presence of thin, discontinuous layers of less resistant materials.

Division No. 4

The carbonate beds in the upper part of Division No. 5 mark a transition to the strata of Division No. 4, which through a thickness of 2,686 feet are largely carbonates. The lower beds of the division weather brownish yellow and very pale yellow; but fresh surfaces vary from pale to dark grey and appear dense or very fine grained. Occasional layers are pink, white faintly tinged pink, or nearly pure white on fresh surfaces. There are some shaly beds towards the base of the division, whose weathered surfaces are frequently a deeper

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brown and yellow. The individual carbonate beds vary from 1 to 10 feet in thickness and often are banded. The varying shades and tints change from layer to layer, though successive zones are largely of one general colour. Such beds continue through a thickness of 950 feet, though near the top there appear a few beds of pink carbonate and several thinly banded grey and greenish zones, with streaks, dashes, and lines of nearly black chert marking the bedding planes in several layers. These beds, nearly 1,000 feet thick, have been referred to as carbonates rather than limestones, since the brownish weathering so characteristic of most of them and the further fact that most if not all these rocks do not effervesce very freely in cold acid, indicate they are not pure limestones but, possibly, magnesium-iron-carbonates.

Many layers in the 950 feet of strata above described, especially in the upper part, contain forms to which Moore has directed attention and which he regarded as being due to algæ.[1] These bodies tend to show elliptical cross-sections which in the simpler forms exposed by weathering are marked by an outer, relatively broad, raised zone of closely crowded, concentric but discontinuous dark lines. The central part of the form is usually depressed and frequently free of any prominent signs of structure. On fresh fractures, the structure is no longer represented by concentric lines but by a difference in colour or texture of the whole form. Commonly the material of the form and of the containing rock is carbonate. Occasionally the form is represented by dark chert and then the concentric onion-like structure of the whole is clearly apparent. These bodies are usually close-set, but not touching one another. Their outlines are spheroidal but irregular. In some cases two or more individuals are enclosed by an outer mesh to produce one composite form. In individual beds there is a tendency for the forms to be of one general size and this in different beds ranges from an inch or less to above a foot in diameter. A tendency for the forms to be abundant in one bed and absent from a succeeding bed is characteristic.

Overlying the above measures occurs nearly 1,000 feet of purplish and pinkish weathering limestone, presumably magnesian, pale and dark pink on fresh surfaces. The limestone is finely crystalline and is traversed by thin bands and fragmentary layers of deeper red colour, very dense, apparently argillaceous. This argillaceous material stands out in relief on weathered surfaces and frequently is so disposed as to give an irregular, mesh-like structure.

The remaining overlying 600 feet of Division No. 4 consists of limestones, presumably magnesian, white to dark grey when fresh, but generally weathering in varying tints of yellow to brown. Occasional zones are deep red on the surface and pale pink where unweathered. The rocks are banded, the bands varying in width from almost paper thin up to several inches or even feet. The alternating layers differ in colour and texture and owing to their varying powers of resistance, alternate layers are frequently recessed. In places the banding is very regular, in others the more resistant layers are fragmentary or so irregular in shape and distribution as to form a mesh-like structure.

The strata of Division No. 4 occupy much of Tukarak island and form a wide band extending northward, probably through the whole length of the island. They form the islands between Tukarak and Innetalling islands and are present on the north shore of Innetalling island, but owing to the southward pitch of the anticline that brings them to the surface, they disappear southward on this island beneath the succeeding formations. The strata of this division are broadly exposed on the large island in the north part of Kipalu inlet, already referred to as situated on the course of the next major anticline to the west. Equivalent strata are exposed on the west side of Kasegalik lake; they extend

[1]Op. cit., pp. 420-429.

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northward for a considerable but unknown distance and here again outcrop along the course of a major anticline.

Division No. 3

Overlying the calcareous rocks of Division No. 4 are 723 feet of slates with irregular streaks and small lenses of pale weathering limestone distributed through a few feet at the base. The bulk of the strata are red slates with narrow, pale grey layers, in places closely spaced, in others widely separated. The red slates are in part rich in carbonate. Towards the top, the red strata are interbanded with green or with zones of dark grey which themselves in some cases are finely and regularly banded. The upper part of the division consists of dull greenish and reddish slates with thin interbeds of yellowish weathering quartzitic sandstones.

This slaty division extends southward along the east limb of the anticline on Tukarak island, and occurs on islands to the south and on the north shore of Innetalling island, where by reason of the southward pitch of the anticline the horizon disappears beneath succeeding members of the geological series. The red slates with the underlying and overlying divisions doubtless continue northward on the west limb of the anticline and apparently partly occupy a series of islands that fringe the west shore of Tukarak island.

The red slates outcrop on the east limb of the next main anticline to the west in Kipalu inlet. There they are confined mainly to a limited area on the mainland, since for most of their extent they lie beneath the sea. The same horizon is presumably again repeated on the anticline of the valley of Kasegalik lake, but that district is heavily drift covered and void of exposures in the parts where the strata might be expected to occur.

Division No. 2

The strata of Division No. 2, for a thickness of 500 feet above the interbanded red and green slates, are largely quartzites and dull greenish slates. The quartzites vary from pale coloured rocks which are fine, even-grained aggregates of rounded quartz grains, to dark coloured, nearly black varieties in which the minute quartz grains are scattered irregularly through an argillaceous base or in which the quartz is aggregated in thin layers that alternate with equally thin argillaceous layers.

Above this lower horizon the strata for a thickness of over 700 feet consist of two thick zones of siliceous limestone separated by a relatively narrow zone of quartzites. The calcareous rocks mostly weather with a yellow or brownish tinge, sometimes faint, sometimes very deep. Rarely the rocks are pinkish. On fresh surfaces the strata vary from white to dark grey. In composition they range from nearly pure, finely crystalline carbonates, to quartzites with an abundant carbonate matrix. The finer-grained varieties frequently present a narrow banding due to variations from layer to layer in the proportions of the siliceous matter.

Above this calcareous horizon, the rest of the division for a thickness of 450 feet to the base of the iron-formation consists of quartzites with occasional thin layers of very siliceous limestones. The quartzites on fresh surfaces vary in colour from nearly white to dark grey. On weathered surfaces they are mostly yellow or pink, apparently as the result of the decomposition of a carbonate which is invariably present, though usually in very small amounts. Some zones are darker and finer grained than the bulk of the strata, but, save for the carbonate, the rocks seem almost entirely composed of minute, rounded, close-set clastic quartz grains. Slight variations in the size of the grains char-

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acterize different layers. In general the rocks are massive and the individual zones structureless, but at various horizons bedding is very apparent, especially in the case of the darker-coloured varieties.

The above-described quartzitic division with its interbedded carbonate zone, everywhere directly underlies the iron-formation. The upper, nearly pure quartzitic member always has much the same general character and thickness, but the number and thicknesses of the calcareous bands in the lower part of the division appear to vary from place to place, although remaining fairly constant over considerable areas.

This division outcrops on the east side of Tukarak island, striking north and south, and doubtless also occurs on the west side of the island on the west limb of the anticline. The strata of this horizon extend southward into Innetalling island, outcropping in the central valley southward to where this valley narrows and becomes floored with drift. On both sides of Kipalu inlet, on the opposing limbs of the next anticline to the west, the quartzitic horizon is exposed at intervals on projecting points, and on islands, and in the north it outcrops nearly continuously for 8 miles. In all probability the quartzite occurs along the next anticline to the west, in Kasegalik Lake valley, but the parts of this district seen, and in which the quartzite might be expected to occur, are drift covered without rock outcrops.

Division No. 1 "iron-formation"

The "iron-formation," or "Keepalloo" formation as Moore named it, abruptly succeeds the underlying quartzite. The strata of the two divisions are not interbedded, nor are any gradational or intermediate forms present. The iron-formation along the general line of section has a thickness of 365 feet, is a bedded formation, and at certain horizons at least, carries some undoubted clastic material. It varies in thickness somewhat from district to district and is variable in its general characters, though the order of succession is, in its broad outlines, everywhere much the same. A full description of the iron-formation and its distribution is given in the succeeding chapters.

EFFUSIVES

The top of the iron-formation wherever seen is followed by a thick sill of diabase. Above this sill in most places is a layer a few feet thick of black, carbonaceous shales, that is presumably a part of the iron-formation separated from the main body by the intervening sill. Above occur sheets of diabase, presumably flows, which form the uppermost strata exposed on the islands. These effusives, so far as seen, are of dark, fine-grained diabase or basalt, not amygdaloidal but generally with an ellipsoidal structure for the most part so well developed that vertical faces of the basalt usually appear as if composed of closely set, spheroidal forms of widely varying sizes. In various instances, however, the lower part of a sheet here and there lacks the ellipsoidal structure. In such cases, in vertical sections, the non-ellipsoidal portion was seen to extend from the base upwards to varying heights and to merge laterally and vertically into the ellipsoidal mass. The basalt, presumably of effusive origin, apparently occurs in a series of flows of varying thickness, in some places resting directly on one another, in other places parted by thin layers of dark shale or limestone. In one section at least twelve sheets of basalt are present in a thickness of 200 feet. These basalt sheets form the summit of the stratigraphical column and their upper limit is an erosion surface representing an unknown, destroyed thickness. Their original volume may have been much greater than the greatest thickness seen, namely 200 feet.

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The effusives and the immediately underlying sill now outcrop over much of the eastern part of the islands. They occur along the east side of Tukarak island and on a series of narrow islands fringing the west shore. They continue southward as narrow ridges on both sides of Innetalling island and form all the islands south of this. The effusives occupy the greater part of the long peninsula and the long island south of it that separate Omarolluk sound from Kipalu inlet. The same rocks form nearly the whole of the ridge separating Kipalu inlet from the valley of Kasegalik lake and extending northward to the northeast shore of Flaherty island. How extensively the basalt may be developed over the western part of the islands is unknown, but since diabase is reported to form the southern shores of that part of the island group, it is probable that the effusives are largely developed, though northward it is probable that the underlying strata outcrop.

INTRUSIVES

As already stated the main part of the iron-formation is, so far as known, everywhere directly succeeded by a sheet-like body of diabase. This is variable in thickness, perhaps ranging between 50 feet and 100 feet. The rock is a normal, olivine-free diabase, of medium, even grain save at its upper and lower surfaces where it is fine grained. The sheet is characterized by partings giving a columnar structure. Ellipsoidal, vesicular, and flow structures were nowhere seen. The lower contact in general conforms to the bedding planes of the underlying iron-formation, but in detail this apparent conformity is found to be fictitious. The contact plane locally rises and falls. In places it sinks 20 feet or more in an horizontal distance of 100 feet and occasionally the plane of contact truncates the dark slaty rocks of the underlying iron-formation. In several instances tongue-like projections of the sheet were seen following bedding planes in the iron-formation, splitting off layers several hundred yards long and a few feet thick.

At its top, this universal sheet is either followed by a few feet of dark, argillaceous shales separating the diabase from the overlying ellipsoidal basalt, or else the effusive basalt rests directly on the diabase sheet. The overlying thin, shaly parting though not continuous is very persistent and—as along the east side of Kipalu inlet—may be seen to extend for miles with scarcely a break.

The crosscutting character of the lower boundary of the diabase sheet, its columnar habit, and the lack of vesicular, ellipsoidal, or other structures characteristic of surface flows indicate that the rock mass is a sill which has intruded the strata at or just beneath the base of the basalt flows. Other diabase sills, but none comparable with this in extent, occur in the iron-formation and underlying members of the Belcher series. Thick sills measuring 50 feet or more, as well as much thinner ones, were seen in the iron-formation on Tukarak and Innetalling islands. Examples of sills in lower members of the Belcher series were seen on Tukarak island, along the shores of Kipalu inlet, and at the head of Kasegalik lake.

The sills which occur below the top of the iron-formation, unlike the uppermost sill, appear at different horizons in different sections and none were seen more than a few miles long while most of them extend for only a few hundred yards. Some are, as mentioned, 50 feet thick, or more; others are less than 15 feet thick. Each sill tends to occur at a constant horizon throughout its length, but possibly, as noted in various instances, the sills may in most cases pass from one horizon to another either very gradually or in a series of small, abrupt, step-like jumps. Local complexities in the structure of the containing strata, such as

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abrupt reversals in the direction of the dip, small corrugations, etc., were noted in various places in the immediate vicinity of the sills, and perhaps some casual connexion exists between these structural features and the intrusion of the sills.

Besides the sills there are less regular-shaped bodies of diabase. On the west side of Kipalu inlet for example there is in the iron-formation, close to the water's edge, a vertical body of diabase that outcrops at intervals for several hundred yards. In part its boundaries are quite irregular, the mass thinning and thickening and sending out tongue-like extensions along the strike. It is possible this mass is located along a fault plane, for the bordering rocks are in part locally disturbed.

As already stated, it is not impossible that the large bodies of diabase situated on the anticlinal axes that respectively traverse Tukarak island and Kipalu inlet, are intrusives. If they are, they may be of the same general age as the widely occurring sills.

Geological Structure

The geological structure of the eastern part of Belcher islands is that of a series of broad folds trending approximately north and south, whose positions are indicated by the major physical features of the island group. In the east an anticlinal axis passes from north to south through Tukarak, Innetalling, and the islands beyond. On Tukarak island the anticline plunges to the north. To the south of Tukarak island it plunges gently southward so that gradually all but the effusive rocks sink below sea-level. In the south, the axial part of the fold is represented only by a long, narrow seaway between two slender islands of effusive rocks which dip gently away from the intervening channel.

Omarolluk sound, bounding the above islands on the west, is presumably a synclinal basin. Its western limb appears on the long peninsula of the east side of Flaherty island and the long island continuing this peninsula southward. Towards the south, the islands bounding Omarolluk sound converge and thus seem to indicate that the main synclinal form plunges northward.

West of the Omarolluk Sound syncline, an anticline traverses Kipalu inlet. This anticlinal axis from a point near the head of the inlet plunges—like that south of Tukarak island—gently southward; northward, the plunge is in the opposite direction, is more marked, and the effusive rocks at the top of the stratigraphical column close in and almost encircle the head of the inlet.

A third major anticline traverses Kasegalik Lake valley, the synclinal form between this and the Kipalu Inlet anticline being represented by the intervening ridge of effusives. The general structure of the western anticline and of the western part of the islands is unknown but in all probability, is the same as in the east, and possibly ends with a syncline traversing the outermost main island.

The strata of the major folds are affected everywhere by minor folds of the nature of open domes and basins elongated parallel to the courses of the main folds. Locally the strata exhibit still smaller folds, in some cases descending in size to open corrugations measuring a few feet or yards from crest to crest.

The measures appear to be singularly free from faulting. A major fault or zone of faulting may follow the axis of the anticline of Kipalu inlet, for the space at the head of the inlet now occupied either by drift or water seems almost too limited to permit the strata to bend round from the east and west limb of the anticline without rupture. Some evidence of an east-west fault is afforded by exposures in the narrow valley which extends westward from near the head of Kipalu inlet to a bay on Kasegalik lake. At this locality, along the north side of the largely drift-covered valley floor, are several exposures of corrugated and highly disturbed strata. These may mark a fault zone, but if they do, the

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net differential movement must be small, judging from the relative positions of the strata north and south of this limited zone of disturbance. As already stated, local irregularities—in some instances very pronounced in character—occur near some of the diabase intrusions. These irregularities do not extend far from the igneous body.

Consequent upon the geological structures affecting the strata, the various horizons outcrop in bands running north and south and gradually sinking in both directions beneath sea-level. Along their courses the bands locally rise and fall through the operation of the minor folds. For the same reason the outcrops of the bands that traverse relatively level districts may follow curving courses or be repeated in closed forms to one side of the main band. In general, the strata in the axial areas have comparatively low angles of dip, whereas on the limbs of the folds high angles of dip up to vertical are common.

Correlation

The upper part of the Belcher series, as has been pointed out by Moore,[1] is almost certainly the equivalent of the upper part of a group of strata that occur at intervals on the islands bordering the east coast of Hudson bay from cape Jones north to Portland promontory and in places, as around Richmond gulf, outcrop on the mainland itself. The strata in question have been named by Leith,[2] the Nastapoka group. To an underlying series, the same author has given the name Richmond group[3] since he supposed the lower group was unconformable beneath the upper. Low[4] has given many details regarding these groups of strata which he believed formed one conformable assemblage whose middle member is that which Leith called Nastapoka. In the following table are given in descending order, condensed statements of various sections as measured by Low, together with two sections measured by the present writer, one on Long island, and one on Belcher islands. In the table, the sections are arranged in order from north to south:

No. 1, north end of Long island, north of cape Jones on east coast Hudson bay.
No. 2, Manitounik islands, 55 miles northeast of Long island.
No. 3, Little Whale river, 85 miles north of Manitounik section.
No. 4, Richmond gulf, south shore of, 12 miles north of Little Whale river.
No. 5, Richmond gulf, south shore of, east of above.
No. 6, Belanger island, opposite Richmond gulf.
No. 7, Belcher islands.

Thicknesses in Feet

Locality No.	1	2	3	4	5	6	7
Iron-formation	340	82	.....	.....	.....	255	365
Quartzites, etc	60	778	118	145	239	294	1,147
Slates	.....	.....	.....	.....	.....	.....	723
Limestones	150	.....	334	168	230	70	2,686
Quartzites (mainly)	.....	.....	150	.....	.....	.....	1,646
Slates, etc	.....	.....	.....	.....	.....	.....	705
Limestones	.....	.....	210	.....	.....	.....	.....
(Unconformity)							
Arkose	.....	.....	175	.....	.....	.....	.....

[1]Op. cit., p. 415.

[2]Leith, C. K., "An Algonkian Basin in Hudson Bay—A Comparison with the Lake Superior Basin," Econ. Geol., vol. 5, pp. 227-246, 1910.

[3]"*Richmond Group*". Since a division of the Ordovician has long been known by this name, it is here suggested that the Precambrian formation in question might be renamed, the Richmond Gulf group.

[4]Low, A. P., "Report on an Exploration of the East Coast of Hudson Bay, etc., etc.," Geol. Surv., Can., Pub. No. 778, 1902.

"Report on the Geology and Physical Character of the Nastapoka Islands, Hudson Bay," Geol. Surv., Can., Pub. No. 819, 1903.

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In the case of Section No. 3, at Little Whale river, the arkose at the base belongs to Leith's Richmond group which, according to Low, is 2,000 feet or more thick in some sections on Richmond gulf. The overlying strata of section 3 and their equivalents in the other sections, together with the iron-formation, constitute the Nastapoka group. The variations from section to section, in the thicknesses of the different members, are in part due to the fact that, except in the case of section No. 7, the lowermost members are not accessible for measurement and the same condition holds with respect to the uppermost members of some of the sections. There is, however, a real variation in thickness from place to place and, in the case of the section on Belcher islands, the members below the iron-formation are much thicker than elsewhere. The validity of the correlation of at least the upper part of the Belcher series with the Nastapoka group rests on the general similarity of the rock succession, on the geological structure which indicates that the strata have all passed through a common history since their formation, and on the lithological characters of the individual members. The equivalence of the lower part of the Belcher series with the lower part of the Nastapoka group as developed at Little Whale river (section No. 3) is open to doubt. It may be that the lower 5,000 feet of strata on Belcher islands represent some part of the time interval indicated by the unconformity at the base of the Nastapoka series, or it may even be that sedimentation in the Belcher Islands district was continuous from Richmond Gulf group time into and through Nastapoka time.

As regards the correlation of the Nastapoka series and, therefore, also of the Belcher series, with the formations of the Lake Superior region, it does not yet seem possible to add anything of value to the statement of Leith, namely, . . . "while, therefore, a satisfactory correlation, in the nature of the case, is impossible, one familiar with Lake Superior geology is tempted to regard the Nastapoka series as of Animikean age."[1]

[1]Op. cit., p. 245.

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CHAPTER III

THE IRON-FORMATION

The iron-formation is the uppermost sedimentary member of the Belcher series and everywhere rests on a thick quartzite member from which it is sharply divided. Upwards it is bounded by a series of basaltic flows, but for convenience the upper limit is taken as being marked by the base of a thick diabase sill intruded along, or very close to, the contact of the basaltic flows and the underlying iron-formation. The sediments and overlying flows lie in a series of parallel long folds the arches of which have been partly eroded. The iron-formation, once continuous over the whole district, is now confined to certain areas where it is largely concealed by the overlying volcanic rocks. It appears at the surface only along the edges of these areas in long, narrow bands outcropping on the sides or at the foot of steep slopes surmounted by the diabase sill and the basaltic rocks.

The position, extent, and attitude of the various bands of the iron-formation are detailed in Chapter IV. The outcropping bands form four areas, which in order from west to east may be named: (1) the Kasegalik Lake area, (2) the Kipalu Inlet area, (3) the Innetalling Island area, and (4) the Tukarak Island area.

Stratigraphical Succession and Character

KASEGALIK LAKE AREA

The Kasegalik Lake area is situated in the northeast part of Flaherty island. It includes the southern part, 5 miles long, of a band of the iron-formation that outcrops along or close to the east shore of the lake; a second band 2 miles long that outcrops 1½ miles to the east along the west shore of the head of Kipalu inlet; and finally a third band-like area extending east and west along the sides of a cross valley and connecting the first-mentioned two bands. These several band-like outcrops occur, respectively, along the west and east sides and across the middle of the flat synclinal form lying between the anticlines of Kipalu inlet and Kasegalik lake.

In this area the whole thickness of the iron-formation is nowhere exposed. The lower part on the Kipalu Inlet side lies below sea-level, and on the Kasegalik Lake side, it is everywhere drift covered. The greatest exposed thickness is 220 feet. This represents, presumably, not more than the upper two-thirds of the formation, for in the other areas the total thickness ranges from 320 feet to more than 400 feet. The strata are divisible into two members and the division is so clearly indicated at many places, and is so persistent as to justify assuming that it marks a natural plane of division occurring throughout the area at a single definite horizon, although, from place to place, the overlying strata vary somewhat in thickness. For convenience in describing the strata, the measures below and above this dividing plane will be referred to, respectively, as the Lower Division and the Upper Division.

Lower Division

The Lower Division, on the Kipalu Inlet side, is exposed to a depth of 100 feet below its summit; on the Kasegalik Lake side only the upper 50 feet anywhere outcrop. The lowermost 50 feet of strata from the lowest exposed beds

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up to an horizon 50 feet below the summit of the Lower Division are fine-grained, in part dense rocks that break readily along slate-like partings spaced parallel to the bedding at intervals of several inches or less. The strata for the most part weather dark, dull red or brownish red. On fresh fractures they are a pronounced red, brownish red, or purplish red, with interbedded dark grey and black layers forming zones 1 to 7 feet thick. At the top and bottom of the dark-coloured zones, the dark grey or black and the red strata are thinly interbedded and, usually, if not always, each of the dark-coloured layers grades quickly upwards into the succeeding reddish layer.

The individual dark layers vary in thickness from several inches to much less. They are for the most part unbanded and very dense, but some show distinct bedding indicated by lines and very narrow bands of black and different shades of grey. Many of the dark grey layers weather brownish, but the black beds do not change colour on weathering. Cold acid causes no perceptible effervescence, but frequently the beds on weathered surfaces are minutely pitted along narrow zones, presumably because of the removal of a carbonate. The rocks resist a knife or are scratched with difficulty. The harder varieties have a splintery or semi-conchoidal fracture. One specimen examined in thin section under the microscope was found to be composed of very fine-grained material so turbid as to appear dark grey by transmitted light and in part, at least, seemingly aggregated in faintly indicated oval areas varying widely in size but averaging about 0·25 mm. in diameter. In addition there appear minute, wisp-like black opaque streaks, perhaps of magnetite, arranged roughly parallel with one another and with the longer axes of the vaguely discernible oval areas, giving a foliated or bedded appearance which is further emphasized by variations from band to band in the density of the turbidity of the general section. The material composing the ovoid bodies is exceedingly fine grained and not determinable, but was judged to be largely silica and carbonate.

An example of the softer varieties of the dark rocks, examined in thin section, appeared as a very finely granular mass of a somewhat turbid carbonate. The carbonate varies somewhat in coarseness from layer to layer and is abundantly accompanied by minute shreds of a green—in part yellowish-green—mineral, these shreds being more plentiful in occasional very thin layers than elsewhere. A very few minute, perhaps clastic, grains of quartz are also present. The green mineral may possibly be an iron-bearing compound analogous to greenalite in composition. The carbonate is presumably ferruginous also, a sample of the rock assaying 13·2 per cent metallic iron.

The more abundant red rocks form layers, some of which are unbanded, but most of which show a very distinct banding due to minute variations in texture and colour in bands varying in width from several inches to a small fraction of an inch. The adjoining layers grade into one another. Some of the red layers are dense, moderately soft, and look argillaceous, but most have a granular aspect, though so fine that the individual grains are not discernible even with the aid of a powerful lens. None of the more normal red rocks of this part of the section in the Kasegalik Lake area were examined in thin section, but it is presumed that they are of the same general nature as examples from the Lower Division in other areas. These proved to be composed largely of very fine-grained silica or carbonate usually masked by a great abundance of dust-like red and black matter presumably hematite (perhaps hydrous) and magnetite.

In both the red, and the dark grey and black strata are occasional distinctive layers up to an inch in thickness that pinch and swell along the strike or end to reappear, after a short interval, along the same horizon. In some instances, instead of distinct layers, a series of flattened lenticular bodies up to

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3 inches in length occur in narrow zones. The material of these irregular layers and lenticular bodies is dark red or purple, has a finely granular texture though the individual grains are not discernible to the unaided eye, and seems responsible for the momentary brisk effervescence frequently producible by applying acid to unweathered surfaces. With a lens, minute red, grey, and black granules are visible. In some instances relatively large cleavage faces up to an eighth of an inch in breadth of a red carbonate may be seen enclosing the minute rounded forms. On weathered surfaces the material is frequently minutely pitted, due, seemingly, to the removal of very finely divided carbonate. Material apparently similar to that of the distinct layers also occurs disseminated through zones sometimes so thin as to appear as lines rather than bands. In the case of the dark strata, this finely divided matter is in places sufficiently abundant to give a reddish tint to the rock.

A thin section of one of these purple layers occurring in the dark grey beds proved to be an aggregate of turbid, reddish stained, rounded grains of carbonate averaging about 0·5 mm. in diameter, accompanied by opaque, red hematite grains of similar outline and size and a few grains of magnetite. The rock is a ferruginous carbonate containing by chemical analysis 12·8 per cent metallic iron. A thin section of one of the very similar-looking layers in the red strata appeared under the microscope as a rather even, fine-grained aggregate of clear carbonate in irregularly oval grains averaging 1 mm. in diameter, of turbid and reddish-stained carbonate, of opaque red material presumably hematite, and of magnetite. Large formless grains of carbonate also compose irregular bands, which are apparently of secondary origin, since they reveal remnants of the rounded outlines of the normal grains. The very abundant hematite also seems to be secondary; it occurs as films surrounding the magnetite grains, and all gradations are present from nearly pure carbonate grains with only a few specks of red to grains completely opaque red. Possibly the carbonate was originally ferruginous, but has since been partly transformed to non-ferruginous carbonate, and the iron oxide has been set free.

In the red and dark grey strata are occasional thin layers, in some instances several inches thick, of very dark, faintly greenish, cherty-looking material having a semi-conchoidal fracture and in a general way resembling some of the harder, dark layers. To the unaided eye, the material appears dense, but with a lens very minute granules are visible, some reddish, others greyish or black and not so clearly distinguishable as the red forms. Minute grains of grey-brown carbonate occur here and there in irregular aggregates. Under the microscope, the rock appears composed of an exceedingly fine-grained, almost cryptocrystalline, colourless base presumably of silica, crowded with very small, ovoid bodies, averaging 0·5 mm. in diameter. A few of these bodies are of magnetite or of a green mineral, perhaps greenalite. Most of them are of silica so fine grained as to appear almost dense, and they vary from such as are clear and colourless, save for a turbid, yellowish margin, to others wholly yellowish or faintly greenish, somewhat turbid looking, and appearing red stained in reflected light. Many green, shred or lath-like bodies are present, perhaps of greenalite, and many similarly shaped individuals are opaque and are red in reflected light. Carbonate is present in single formless grains and aggregates of the same and seems younger than the other constituents and probably is of secondary origin.

On the Kipalu Inlet side strata such as form the lower 50 feet of the section continue upwards, but in a thickness of about 10 feet their general character gradually changes to that of a second phase 40 feet thick that continues to the summit of the Lower Division. On the Kasegalik Lake side this second phase is 50 feet thick and no lower strata are there exposed. In the upper phase the

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strata, are more massive and lack the easy, slate-like parting. The bulk of the measures are conspicuously banded, have a finely granular texture, and are very ferruginous, containing much magnetite as well as hematite, and assaying at various horizons for thicknesses of 10 to 15 feet, 35 per cent to 45 per cent metallic iron. The general colour is red, in places very dark because of the abundance of magnetite. Black or faintly greenish black zones several feet in thickness occur at different horizons in different sections. The true black layers are largely composed of finely granular and crystalline magnetite which gives the rock a faint sheen. The faintly green beds are poorer in magnetite. The assemblage is also characterized by a great abundance of the cherty-looking material previously described as occurring very sparingly in the underlying beds. In places this cherty-looking rock occupies as much as 20 per cent of the section.

The general colour of the upper phase of the Lower Division is, as stated, a deep red verging on purple. Beds up to several inches in thickness have a uniform colour, but these alternate with others as thick which are characterized by dark, very narrow streaks spaced at varying intervals or so grouped as to resemble a single, nearly black layer. Examined with a lens, the red layers are seen to be formed of close-set, minute grains mostly red, but in many cases black and then composed of magnetite. The same structure holds in the case of the dark-coloured streaks and bands, but in them the black magnetite grains predominate.

Other beds which occur with those just described are purple, more compact, less granular in appearance, have an irregular fracture in some cases verging on conchoidal in character, and possess a slightly vitreous lustre. Such rocks, when closely examined with a lens, are seen also to be composed of red, grey, and black grains. Other beds, which form layers in some cases several feet thick, are very dark and faintly lustrous from the great abundance of magnetite which in some examples occurs very largely in minute octahedra. Occasional thin layers are of a brighter red than the average, are very fine grained, and have an argillaceous appearance. Some layers are very dark, slightly greenish, carry abundant grains of magnetite, but lack the reddish and grey grains.

The finely granular, banded red and purple beds when examined in thin section under the microscope present evidence of having once been composed of minute bodies closely set in a matrix. In every instance two general types of bodies are indicated, one hereafter referred to as being granules, tending to have rounded or elliptical outlines and the other to have elongated, lath-like or more irregular shred-like shapes.

The granules in some thin sections are predominantly of silica, in some cases microcrystalline, in other slides cryptocrystalline. In some cases, these granules are irregular mixtures of finely granular silica and minute specks of a brilliantly polarizing mineral which, possibly, is calcite. In one instance the colourless granules were almost wholly calcite. The colourless granules contain in varying proportions in different sections, and in different bands in a single section, opaque, dust-like material. In some cases, this mineral is red by reflected light and considered to be hematite; in other cases it is black by reflected light and either dull or with a metallic lustre, and is presumably magnetite.

In every section may be observed what appear to be all gradations from a clear, colourless granule to a perfectly opaque one, either red, dull black, or black with a metallic lustre. This phenomenon apparently indicates that the granules have been subjected to a process of replacement by iron oxide.

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The elongated, frequently shred-like forms are in part composed of a green mineral whose colour varies from grass green through yellowish green to greenish yellow or brown, one tint of colour being usually characteristic of each section, as though the variations in colour might be of secondary origin. The mineral also forms rounded or plate-like individuals. These show no pleochroism or absorption of colour, but the elongated forms usually do, though frequently only faintly so. No decided cleavage is apparent, but the elongated individuals in some cases vaguely show a parting or appear as though bent. Between crossed nicols the mineral in some cases shows low interference colours, in other cases colours of a high order. The mineral is presumably greenalite or some analogous ferrous silicate. In many cases it forms a small part of the otherwise colourless granules and in such instances seems present as minute specks or as a mere film.

In different thin sections, as in the case of the rounded granules, all gradations may be observed from a homogeneous individual of the green mineral to one that is perfectly opaque and either red or black by reflected light. Presumably the green mineral also has been subjected to a process of replacement by iron oxides.

In some instances the unaltered and variously replaced granules and individuals of green mineral are set in a colourless ground of silica, either finely granular or showing radiating and sheaf-like structures. In most cases the ground is composed of magnetite or of magnetite and hematite. The hematite when sparingly present is irregularly disposed; when abundant it occurs in minute, elongated patches. In the base of iron oxide are also clearly visible, by reason of a difference in texture, etc., rounded or oval bodies of magnetite and more irregular forms of lustreless black, iron oxide, presumably representing replacements of the green mineral. Much of this formless ground may represent replaced granules, but some part, at least, is a replacement of the matrix in which the granules once were set.

Banding is indicated in all thin sections by variations in proportions of the different constituents, by, in nearly every case, a parallelism of the elongated green forms, and, less generally, by a parallelism of the longer axes of the colourless granules. The granules show much variation in size not only from section to section but within individual sections. Occasional individuals are four or more times larger than the next average size, and in each section many are considerably smaller than the average. This average size varies from section to section between 1 mm. and 3 mm. in diameter. The outlines of the forms are variable, but in general tend to be round or elliptical and are never angular.

An example of the red, dense, argillaceous-looking rock which forms occasional thin beds, when examined in thin section, proved to be solidly opaque, and composed chiefly of hematite, but with considerable magnetite in dust-like particles and small grains. The hematite has a streaked look and appears as though it might be in small aggregates, some oval in outline, but the bulk quite irregular in shape.

The more compact, less distinctly granular beds that have a faintly vitreous lustre were found when examined microscopically to have a colourless base of silica. In one instance this appeared as a fine-grained mosaic of quartz in part distinctly arranged in granular layers about rather widely spaced granules. These are small, of rather even size, and tend to be elliptical in outline. A majority of them show some magnetite and many are solid magnetite or magnetite with a partial narrow rim of hematite. Others contain near their centre a minute grain or two of quartz, or a small centrally disposed area of comparatively coarse, quartz mosaic. Gradations occur to forms in which magnetite composes only a border or partial border around a quartz mosaic, and some granules are almost entirely of silica either comparatively coarse or so dense

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as to appear structureless. In some granules there are a few shreds of a grass green or a yellowish, micaceous looking mineral and some granules are almost entirely of such material.

Another example of one of these dark bands still denser and more siliceous looking than the preceding, when examined in thin section, was found to consist largely of silica varying in grain from microcrystalline to very finely granular, the different textures being so disposed as to faintly indicate the presence of small close-set granules for the most part oval in outline. Through the section abundant magnetite occurs in formless, small grains and dust-like particles lacking any special structural features. The green mineral is also abundantly present in small shapeless grains and larger aggregates of the same. Calcite is common in small and larger grains and aggregates of the same and some of the individuals have rhombohedral outlines.

Examples of dark, nearly black rock varieties so rich in magnetite as to have a distinct lustre, in thin section appeared composed in about equal amounts of magnetite and the undetermined green mineral which presents elongated forms seldom ragged, lying parallel to one another. The magnetite for the most part is in formless aggregates of apparently both irregular and crystalline grains, the latter presenting rectangular boundaries to the adjoining areas of green mineral. A small amount of carbonate is present and a few granules of cryptocrystalline silica.

In a thin section of another example the rock proved to have the same general mineralogical composition, but the individuals of the green mineral do not show any common orientation and the relative proportions of magnetite and the green mineral vary from place to place in the thin section. A thin section of a magnetite-rich, dark variety having a faint purplish tinge was found to be composed of a continuous matrix of magnetite with small vague areas and stainings of hematite. This matrix holds isolated granules and what appeared like remnants of granules of the green mineral; also dull black, opaque, shred-like patches which are presumably magnetite pseudomorphs after the green mineral. A thin section of a nearly black, faintly greenish type not so rich in magnetite as commonly was the case, proved to be largely composed of the green mineral holding much magnetite in formless grains and small granular aggregates, and a few elliptical granules of calcite.

In the upper part of the Lower Division and occurring upwards in increasing amount are irregular layers and thin zones of dense, dark, faintly greenish, or reddish, or reddish mottled green, chert-like looking material such as has been described as occurring at wide intervals in the lower beds. In the uppermost horizons, this chert-like material is very abundant; in places it composes 20 per cent of the section. The material has a semi-vitreous lustre, a semi-conchoidal fracture, and, unless it is very closely examined, appears dense and structureless. Examined with a lens, it may be seen to be composed of minute granules, mainly red but with many of grey and black shades. In some instances the individual grains are close set, in others more widely dispersed through a dense matrix. A thin section of a purple mottled type, under the microscope was seen to be composed predominantly of very fine-grained silica. The silica varies slightly in grain from one small area to another, making it apparent that the rock is essentially composed of close-set granules of such material. Opaque, dust-like material, in places black, in others red, frequently outlines the granules or occurs in varying amounts within the granules. In some instances small granules or elongated forms were seen to be composed solely of the opaque matter which undoubtedly is both magnetite and hematite. A small amount of the usual green mineral is present in very small individuals and larger shreds. Some turbid carbonate also occurs in aggregates of irregular outlines.

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In the zone extending downwards for some 30 feet from the top of the Lower Horizon, this "cherty" material, though always conspicuous, varies in amount from section to section. The locally decreased amounts may in part be compensated by an increase in material intermediate in character between the chert-like matter and the normal ferruginous strata, but this point was not determined. The boundaries of the "cherty" layers appear sharp, but close inspection shows that at top and bottom they grade into the adjacent strata. Along the strike a layer may be continuous for many yards or only for a few feet. Frequently the layers are not continuous, but consist of a series of elongated lens-shaped bodies appearing along a definite horizon or within a narrow zone. In various instances a relatively thick layer may be seen to give way to a number of separate irregular bodies lying in material like the normal strata, but so disposed as to appear like remnants of a former extension of the solid layer. The boundaries of the smaller masses of chert-like material appear in sections as smooth curves, but the masses are frequently embayed and of fantastic outlines. In some instances centrally disposed portions of the masses are of the same composition as the surrounding strata. It is noticeable where this chert-like material is most abundant that the partings marking the bedding in the enclosing ferruginous strata are arched, hummocked, curved, and otherwise confusedly irregular in their mode of development.

Upper Division

The strata of the Upper Division of the iron-formation are well exposed in many places along Kipalu inlet. The upper portions are also exposed on the sides of the cross valley and the bay on Kasegalik lake. On the slopes facing Kasegalik lake to the north and south of the bay, the strata are not so well exposed, but outcrops are sufficiently numerous to show that the Upper Division everywhere possesses the same general characters and is divisible into three members.

The lowest member abruptly succeeds the ferruginous strata at the top of the Lower Division, and has a thickness of 50 feet. At the base, for several feet in thickness, the beds are very dark green and dense of grain. The lowermost layers have close-set, slate-like partings whose surfaces have a faint sheen due to a multitude of minute, shining specks which, under a lens, appear tabular. These beds are moderately soft. The succeeding layers are harder, break with an irregular fracture, and the abundant, glistening, minute scale-like material is no longer oriented parallel to the bedding planes. A thin section of the lower, softer strata showed a bedded rock mainly formed of a very fine-grained, turbid, greenish aggregate carrying innumerable small clastic grains of quartz and feldspar. Different layers vary in the proportions of the clastic material, and some thin layers are clear green, with larger clastic grains and with the green mineral in distinct grains of a grass-green colour. But by far the greater part of the section appeared as a fine-grained, confused, greenish aggregate with many slender, apparently cleaved, green, pleochroic individuals resembling the ordinary green mineral and so arranged as to give a distinctly foliated appearance. Possibly much of the turbid base is a carbonate and many minute clastic grains may enter into its composition. No iron oxides were detected. The upper compact beds, in thin section, resemble the above, but the abundant clastic grains are much larger and are distinctly composed of quartz and orthoclase and plagioclase feldspar. A few grains of magnetite were visible and it is probable that much of the dust-like matter causing the turbidity of the green matrix is magnetite.

Upwards in the rock section the massive dark strata revert to the more slaty form and gradually assume a dark reddish or reddish-purple colour. The

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minute, shining, scale-like particles are always abundant and, apparently, according as these scales are or are not oriented parallel to one another, the rocks have or have not a slate-like parting. Still higher the rocks assume a pronounced reddish colour with thin, coloured layers marking the bedding. Towards the top, the beds again become a dark, faintly greenish grey; they vary from shaly to slaty to compact, are mostly quite soft, very dense, and look not unlike true argillaceous strata.

The middle member of the Upper Division seems to have a thickness of between 25 and 30 feet, but decreasing rapidly at the north end of the exposures on Kipalu inlet and perhaps there disappearing altogether. On the shore of Kasegalik lake, towards the south end of the outcrops, the strata also seemed to become thinner. This member on the whole weathers greyish with yellowish and brownish tinges and the strata lack regular bedding and are blocky in character.

The lowest part of the member is a compact, dark grey nearly black rock, very fine grained to chert-like in texture. The coarser parts have a granular look, are rough to the touch, and with the aid of a lens may be seen to be composed of rounded forms, mostly dark grey but in some cases red. In thin section, the rock appeared as a mosaic of minute quartz grains of fairly uniform size with close-set, rounded, elliptical and irregularly shaped bodies perhaps averaging 6 mm. in diameter. These bodies are composed in varying proportions of quartz grains like those of the general base, magnetite and the usual green mineral with a small amount of carbonate. In some instances these bodies or granules are distinguishable only through the presence of a narrow rim of the green mineral, with or without magnetite. In other cases these two minerals in varying proportions lie between some or most of the grains of quartz within the granule, and examples show gradations from granules such as these to others composed almost solely of magnetite or, more commonly, of the green mineral with varying amounts of magnetite. On the other hand, there are areas in which the outline of the granule is only partly indicated. The general appearance is that of a rock once formed of close-set granules, of whose original characters perhaps only their shapes are preserved and even these in many cases only partly. A thin section of the lower beds from another locality resembles the above in various ways, but the amount of the green mineral and magnetite is considerably less, and the quartz grains of the granules are much larger than those of the base.

The strata of the middle member above its lowermost layers are finely granular and blackish grey or, in some places, pinkish. Some portions carry much pinkish carbonate in minute grains and granular aggregates. The rock frequently holds much magnetite in minute grains and narrow streaks; lenticular-like layers are dark greyish black due to the local abundance of finely disseminated magnetite. On close inspection, the rock is seen to be composed of close-set pale and dark greenish, black and red grains. The rocks weather a dirty brown, are rough to the touch, and vary considerably in grain in apparently an irregular fashion. Such rocks compose the bulk of this member. In thin sections these are on the whole similar to the rocks just described, but in one instance the abundant magnetite occurs wholly in small polygonal crystal forms, disseminated and grouped in large and small aggregates. In another instance, the green mineral is frequently bounded by hematite, or stained reddish, and the relations so expressed appear to indicate that the hematite was derived from the green mineral. This conception, seemingly, is substantiated in the case of another thin section in which the granules are clearly indicated by the difference in grain of the quartz mosaic composing respectively the granules and the base and are further differentiated by the presence of abundant magnetite and hema-

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tite, in some instances the whole granule being iron oxide. No green mineral is present, but the magnetite and hematite are arranged with respect to one another as the magnetite and green mineral are in other sections.

Towards the top of the middle member, the grain of the rocks becomes more variable. Fine-grained, irregular bands or layers occur with others that are much coarser and that in one instance proved to be composed of large granules averaging 8 mm. in diameter. The granules are stained yellowish, composed of coarsely granular quartz, and lie in a relatively fine-grained quartz mosaic.

In the strata of the middle member are occasional layers from a mere film to several inches thick, most of which weather a deep ochreous yellow or brown to depths as great as half an inch, where the weathering abruptly ceases. Such layers are dark greenish grey on fresh surfaces. In general appearance they resemble the main rock body, but in thin section they appear as a structureless, even-grained, granular mass of carbonate, green mineral, and quartz perhaps of clastic origin. Some of these thin layers are dark green and appear dense; when closely examined, however, the material may be seen to be composed of close-set, pale greenish granules separated from one another by very thin, imperfect black rims. In thin section, the rock seemed composed of close-set, uniformly large granules of exceedingly fine-grained silica with varying amounts of a green mineral in minute specks so small as to be almost dust-like. Some of the granules contain scarcely any of the green substance, some are largely composed of it, and others are intermediate in this respect. There are also a few rhombs, some large, of calcite that appear to have developed without regard to the structure of the rock. The matrix in which the granules lie is a quartz mosaic slightly coarser than that of the granules and present in only small amounts, many of the granules touching one another. Other thin layers are compact, dark grey, faintly purplish, siliceous looking, and dense. In thin section one of these proved to be an exceedingly fine-grained aggregate of turbid carbonate and green mineral.

In the upper 3 feet of the middle member occur dark, faintly greenish interbeds which are in part thinly shaly, in part slaty, in part hard massive but argillaceous-like strata. These interbeds are 1 to 3 inches thick. The intervening beds expand and contract in thickness along the strike.

The highest member of the Upper Division appears to vary in thickness between 30 and 60 feet, but for the most part is about 40 feet thick and it may be that everywhere this is approximately the true thickness. It is formed mainly of dark, slaty strata, either faintly green or very dark grey, and for the most part weathers reddish or brownish. The measures are in part thinly bedded, rather soft, in part more compact, and in part, hard, brittle, inclining to be massive. The higher beds show a marked narrow banding in varying shades of dark grey. They are fairly hard and dense, but with indications of a granular texture. Characteristically the brownish or red weathering extends inwards for one-eighth to one-quarter of an inch, ending abruptly along even planes. In thin section one such variety appeared as a dense turbid mass with narrow, opaque, black zones and streaks. Much of the matter is exceedingly fine-grained carbonate but the remainder is too fine grained for closer identification.

In this upper dark member there is usually present one—perhaps in some places several—layers of structureless material such as composes the middle member. A layer from 3 feet to 7 feet in thickness is continuous in the area fronting on the shore of Kipalu inlet and may be the equivalent of layers of the same character seen on the Kasegalik Lake side.

At one place, on the south side of the bay in Kasegalik lake, a 6-inch bed of dense, grey limestone occurs high up on the uppermost member and may be seen to persist along the strike for 100 yards.

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KIPALU INLET AREA

On the east side of Kipalu inlet, the iron-formation forms a narrow band that extends nearly due south from the north end of the tidal basin at the head of the inlet, to where the formation sinks below sea-level. Over the whole distance the band maintains a nearly uniform width of about 350 feet and lies on the west slope of the diabase-capped ridge beneath which the iron-formation dips. The boundaries of the band for the greater part of the distance are closely defined by outcrops of the overlying dark diabase and of the underlying pale quartzite, but, on the whole, the iron-formation itself is poorly exposed. The total thickness of the formation appears to vary from 320 feet to 360 feet or perhaps even a greater amount.

Southern Section

Towards the south of the 10-mile stretch, the general section seems to be somewhat as follows, though as it is based on correlations of partial sections and isolated outcrops distributed over a length of several miles, the results are subject to revision.

The lowest outcropping strata occur about 40 feet above the base of the formation. They consist of thinly-bedded, red, slaty, dense rocks with dark greyish layers, and closely resemble the already described, lowest exposed rocks on the west side of the inlet. Such beds extend upwards for 26 feet to an horizon 66 feet above the base of the formation. The next 26 feet is composed of a bank of granular rock such as forms the middle member of the Upper Division in the Kasegalik Lake area. In this 26-foot bank, seams and lenses of red, dense, cherty-like material are largely developed. The material is not true chert, but is composed of minute granules set in a dense base and in major characters corresponds with the chert-like matter so largely developed in the upper part of the Lower Division to the west.

From the top of this bank for 160 feet, up to an horizon 252 feet above the base, the strata so far as they are exposed are mainly red but are accompanied by thin, dark grey beds mostly confined to zones of varying thicknesses. All the strata possess slate-like partings. They are very largely dense rocks, banded in different tints, and with layers of different degrees of fineness. The coarser layers have a granular aspect, but the individual grains cannot be detected even with the aid of a lens. A thin section of one of the coarser varieties consists of a base of opaque, dense, red, hematitic material minutely flecked and streaked black. Small oval areas of what appear to be turbid carbonate occur through this base, lying with their longer axes parallel and more numerous in certain minute bands than elsewhere. The arrangement of the granules gives a banded structure which is further emphasized by minute bands holding abundant minute clastic grains of quartz, orthoclase, microcline, and plagioclase feldspar. An occasional oval area of carbonate occurs in these narrow bands rich in clastic material and the clastic grains occur throughout the section. A thin section of a second example of these rocks when examined microscopically showed the same dense, opaque, red base, but the clastic grains are only sparingly present and the carbonate is more abundant.

In these predominantly red beds, in some places if not everywhere, are two horizons, one 185 feet and the other 205 feet above the base of the formation, at which for thicknesses of 10 feet to 20 feet, the strata are highly ferruginous and in general appearance are quite similar to, and apparently almost identical with, the ferruginous strata at the summit of the Lower Division in the Kasegalik Lake area. As in that area the ferruginous beds are interleaved with many thin, irregular layers analogous to the chert-like layers of the western

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area. Some of the ferruginous beds, for a thickness of several feet, are more purely hematite than is usual and are soft, and friable enough to soil the hands.

The abundant, irregular layers referred to in the above are bright red and in part are comparatively coarse, being composed of rounded and shapeless forms which are red, grey, and black and in some instances an eighth of an inch in length. A thin section of this type showed variously shaped granules of widely varying sizes crowded together, the interspaces being occupied by a finely granular quartz mosaic. Some of the granules are wholly of very finely granular silica, others are similar but have a partial or complete rim of red or black, and frequent examples show all gradations between forms such as these and others wholly stained red, or composed almost entirely of magnetite with a thin border and small, irregular, internal areas of hematite.

The predominantly reddish, fine-grained strata with the several ferruginous zones and, low down, the bank of grey, granular rock, extend upwards from the base of the formation for a thickness of 252 feet. Except that they lack a ferruginous member at the top, these strata correspond in position and characters to the Lower Division of the formation in the Kasegalik area, whose nearest outcrops are 4 miles to the west. They are succeeded upwards by a group of strata corresponding to the Upper Division of the Kasegalik Lake area and, like it, composed of three members. These three members, however, seem to be variable in thickness and in places have a combined thickness of not more than 70 feet.

The lowest of the three is about 25 feet thick in most localities, but in places is, perhaps, much thinner. It is composed of dark, shaly and slaty beds, dark greenish on fresh, unweathered surfaces.

The middle member at one place is 21 feet thick and presumably is everywhere of about this thickness. It is of poorly bedded, irregularly banded, "blocky" strata such as compose the equivalent horizon in the Kasegalik Lake area. The rocks weather yellowish, brownish, and reddish, and are granular and rough to the touch. Fresh surfaces vary from light to dark grey to almost black. Some irregular layers are very largely composed of magnetite, others are red and hematitic. One specimen, in thin section, was found to consist of a mosaic of granular quartz varying in grain irregularly from spot to spot and holding areas of magnetite, irregular in outline, in part frayed or wisp-like. A red staining was slightly developed. No features were noticed indicative of the former presence of the usual granules. A second specimen showed a rock composed of large granules crowded together in a quartz mosaic. The granules were of finer grained silica with varying proportions of magnetite, which in many instances merely outlined the individual granules.

The uppermost member in some places at least is 24 feet thick and is composed of dark, greyish and black, slate-like strata with, in the lower part, some red-weathering layers. The beds for a few feet at the top are very dark, in part thinly banded in different shades of grey, and are hard, splintery, dense, almost chert-like. Other beds are softer, unbanded, and nearly black; they effervesce freely with acid and weather brownish in a sharply defined shallow outer zone. Some of these softer rocks carry small ellipsoidal bodies up to one-half inch in length of dark, dense, chert-like material. In thin section an example of the harder, banded type appeared as an exceedingly fine-grained rock composed mainly of silica but with much carbonate for the most part assembled in small irregular areas. The amount of carbonate varies in such a manner as to cause a marked banding. Occasional small vague areas of the silica seem distinguished by texture from the neighbouring matter, but there was no certain indication of the former presence of granules.

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The softer, unbanded rocks as represented by one thin section appeared as a fine-grained, almost dense, turbid mass with tiny frayed and wisp-like areas of black. Both in ordinary light and with crossed nicols, the section seemed to be largely formed of very small, oval aggregates presumably of finely divided silica and carbonate.

Northern Section

Towards the north end of the 10-mile Kipalu Inlet band of iron-formation after a long, for the most part, very imperfectly exposed interval, outcrops become more numerous, but only a partial, imperfect section can be reconstructed. The total thickness of the strata is about 320 feet. The greater part is of red, banded, slaty strata with, as in the south, a band of the grey, compact, blocky rocks in the lower part, but perhaps not everywhere at the same horizon. The upper part, as before, is composed of dark grey and black beds with, in places at least, a layer of the grey, granular rock, thus repeating the threefold division of the Upper Division.

The outcrops of the lower part of the formation consist of relatively soft, almost dense, reddish, in part argillaceous-looking banded strata with some layers less dense almost granular in appearance. In one locality, at horizons between 40 and 85 feet above the base of the formation, are exposures of such beds that weather dark purplish. They are accompanied by thin, nearly black interbeds very dense on fresh surfaces but weathering yellowish and reddish. In these strata are irregular layers 1 to 2 inches thick and still more irregular layers that swell in places to a thickness of 1 foot, of bright red colour and possessing a splintery or semi-conchoidal fracture. The rock in these layers consists of a bright red, dense matrix crowded with elongated, irregular, darker coloured forms varying from minute specks up to others 0·03 inches in length. These forms have mostly minutely wavy irregular outlines and lie with their longer axes parallel with one another. In thin section this rock appeared to be mainly of matter, bright red in reflected light, containing small irregular areas of magnetite and innumerable, elongated, mostly wisp-like areas of colourless, very fine-grained silica. Most of the red material is opaque, but in part was seen to be a red staining on silica.

The thicker layers of the above-described material in many places have a central part that includes irregular bodies of a darker, duller red colour formed chiefly of close-set, grey and black granules of uniform size. In thin section such a rock was seen to be composed of vaguely indicated, comparatively large granules of very fine silica stained reddish and closely packed together in a coarser quartz matrix. A few of the forms are outlined with magnetite. This more definitely granular material also forms homogeneous layers and layers which along the strike grade into the more brilliantly red rock. The relations are such as to suggest that the brighter red variety has been derived from the more normal granule-bearing type.

The banded red strata with the numerous irregular red layers, are succeeded at 85 feet above the base of the formation by a 15-foot bank of the blocky, irregularly banded, granular rock type. It is grey and greenish in colour, weathers reddish and yellowish, and varies irregularly in grain and composition. Many thin, irregular layers of the red "cherty-looking" material are also present. A relatively coarse rock crowded with magnetite octahedra occurs in irregular streaks and bands up to 1 foot in breadth; it has irregular curving boundaries and in many parts holds irregular fragment-like masses of the more normal strata, as if the coarser phases were in some way replacing the finer. In thin sections the coarser type appears as composed of large granules, stained reddish and formed of very fine silica with varying amounts of dust-like or more

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definitely granular magnetite. The magnetite in some cases is uniformly distributed through the granules or is aggregated towards the centres or about the borders; and there are all gradations to granules of solid magnetite. The matrix is a comparatively coarse mosaic of quartz. Much calcite is present, partly in sharp rhombs, partly in large irregular areas, in both cases appearing to have replaced the other rock constituents.

Upwards in the formation, red strata predominate for over 100 feet. At one or more horizons in this interval the beds are highly ferruginous and resemble those occurring at the summit of the Lower Division in the Kasegalik Lake area. At some horizons in these red strata occur zones of very dark, nearly black rocks in part thinly banded and interleaved with pale films and thin layers of pale grey, fine-grained carbonate. The dark beds have an outer ochreous brown or yellow weathered zone. An example of one of these rocks in thin section was found to be composed of innumerable small, clastic grains of quartz, orthoclase, microcline, and plagioclase lying in a very finely granular base of turbid carbonate and still finer particles of the quartz and feldspars. Large, formless areas of carbonate that appear to be secondary were present. A few small grains and shreds of a pleochroic green mineral were noted. The total thickness of the Lower Division is estimated to be 260 feet, much of which is only poorly exposed or not at all as in the case of the uppermost part.

The Upper Division perhaps not over 60 feet thick is as usual composed chiefly of dark strata, and there is evidence of the existence of a band of the grey, granular, blocky rocks.

INNETALLING ISLAND AREA

At the north end of Innetalling island, 20 miles south of the south end of Kipalu Inlet area, there is a narrow valley which extends southward through the middle of the island. This valley broadens out at its north end and is in part occupied by a bay of the sea at whose head is a tidal lake. The iron-formation outcrops on either side of the valley in two narrow bands, 2 miles apart in the north but converging southward as the valley narrows, so that 3½ miles to the south they are only a quarter of a mile apart. These two bands, representing the opposing limbs of an anticline, outcrop at the foot of, and for varying heights on, the slopes of diabase-capped ridges. Only the upper parts of the iron-formation are exposed in the western band, the lower parts being drift covered or beneath water-level. Even the upper parts are much concealed by drift. In the eastern band, owing to minor folds, the formation rises and falls, so that in places the base lies above sea-level, in other places the top descends beneath the water. Considerable sections are drift covered, but in general the upper parts are well exposed. The total thickness of the formation apparently is at least 450 feet and may be slightly greater. As in the Kasegalik Lake area, the strata are divisible into two groups the lower of which is terminated by a ferruginous horizon, and these groups respectively correspond in general characters to the Lower Division and Upper Division of the before-mentioned western area.

Lower Division

The lowermost beds of the iron-formation are exposed only along the eastern band and at only two localities. They abruptly succeed the underlying pale-coloured quartzites. The quartzite and iron-formation are not interbedded, nor are there any signs of gradation of one type into the other. The lower beds for a thickness of 25 feet are mainly dark purplish red, hard, and fine grained. They vary from dense to finely granular in general appearance, but the individual grains are not distinguishable. The rocks are banded, the banding being

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expressed by variations in colour and in grain and by the presence of dark greenish-grey layers. The bands in part are thin, varying from the thickness of a film only up to one-half inch; in part they are broad, and include zones several feet in thickness largely of dark grey to black strata. Adjoining layers grade into one another. In thin sections, one example banded red and purple was seen to consist of minute bands all very fine grained, some nearly colourless, others largely opaque and red by reflected light as though largely of hematite. Magnetite in detached minute grains and dust-like forms is about equally abundant throughout. Very small, angular clastic grains of quartz and feldspar (orthoclase, microcline, and plagioclase) occur in all layers but are most abundant in the clear portions, and in the case of some minute layers largely constitute them. The base of the clearer layers is cryptocrystalline. It possibly is silica and apparently the same material occurs throughout. Some layers contain 50 per cent of very finely granular carbonate; other layers are characterized by very small formless grains of a pleochroic green mineral; and some layers, as already stated, are largely opaque red by reflected light. Possibly this opaque mineral is not pure hematite but a dust-like aggregation in the dense base. Calcite in small rhombs occurs in all the layers.

In some localities at least, at an horizon about 30 feet above the base of the iron-formation, there is a 4-foot bed of the granular, unbanded, blocky rock type, of a dark red colour and comparatively coarsely grained. Examined with a lens the rock may be seen to consist of irregular red bodies apparently set in a grey matrix. In a thin section, a part was found to be composed of large granules most of which are partly or wholly turbid and, where turbid, red stained. These are closely set in a fine-grained quartz mosaic and are composed of granular silica, largely very fine grained but in many instances with a coarser-grained central part. Large rhombs of carbonate lie indifferently in both the granules and the matrix, and there are small patches of a strongly pleochroic mineral arranged in radial and sheaf-like aggregates.

A part of the section contains only angular remnants of the granules and of such portions of carbonate rhombs as lie within or project into the granules. The rest of this part of the section is a granular aggregate or mosaic of quartz varying irregularly in grain but always relatively coarse. This part of the section seems undoubtedly to have once possessed the granules of the normal rock and represents vaguely outlined areas that are macroscopically visible in hand specimens. These areas have a cherty appearance, their borders are frayed, and they appear to merge into the normal rock.

In this zone and in the adjoining strata, are thin layers and detached lenses of bright red material, cherty-looking but in reality composed of minute granules in a dense siliceous matrix such as has already been described in other areas. Above this zone, the strata for several feet are dark purple. They have a splintery fracture and are almost dense in grain, but give indications of a granular texture and exhibit many minute grains with a metallic lustre. In thin section the rock appears as a fine-grained aggregate of colourless and opaque grains. The opaque ones are mainly red by reflected light, but many are of magnetite. Occasional larger grains are distinctly oval in outline and the whole appears as a close-set aggregate of granules barely averaging 0·5 mm. in diameter. The colourless granules are largely exceedingly dense and, presumably, composed of silica. In many instances minute green shreds and scales, and dust-like and larger grains of red or black iron oxide are also present. The green mineral also forms elongated individuals. The bulk of the iron oxides gives indications of occurring in rounded areas corresponding in size and outline to the colourless granules, but possibly the iron oxides in part represent what may have been the matrix in which the granules lay.

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Upwards the strata become more thinly bedded and in the horizons between 50 feet and 60 feet above the base they are banded in different shades of dark purple and brighter red. The red layers are relatively soft and fine grained and are themselves banded. In thin section, this type was found to be prominently banded, opaque layers alternating with others that appear on the whole to be transparent but are actually heavily charged with dust-like opaque material that gives a dark purplish cast to the whole in reflected light. The relatively transparent bands seemed to be formed of minute, irregular, elongated bodies lying with their longer axes parallel. These bodies or aggregates are possibly exceedingly fine-grained silica. They carry countless minute forms possibly of the green mineral. Occasional larger, clear, oval bodies of the same material characterize some layers. The opaque layers by reflected light seem composed largely of hematite, but with abundant magnetite, the two minerals being in minute, irregular, frayed aggregates with their longer axes parallel to one another and to the banding, thus producing a pattern like that exhibited by the relatively clear bands.

In this zone are thin, bright red, irregular layers of the so-called cherty rock composed of minute ellipsoidal and sharply-rectangular bodies, some 0·03 inches in length, set in a dark, dense base. In thin section, the rock was seen to be composed of rounded, ovoid, and irregular forms of widely varying sizes set in a clear colourless matrix of silica, the silica being both granular and in radiating and sheaf-like aggregates. Most of the granules are opaque or nearly so and in reflected light appear wholly red or red with a partial or complete rim of magnetite and small, irregular spots of magnetite. A few smaller granules are wholly of magnetite. Other examples show all gradations from wholly opaque granules to nearly wholly colourless transparent granules composed of fine-grained silica stained red. Carbonate is present in a few small grains in the matrix and, also, in several areas, as assemblages of larger, plate-like forms that lie indifferently in the matrix and in the granules. In some instances, the carbonate is charged with slender, green rods.

In the red cherty-looking rock are occasional streaks, small lenticular patches, and as noted in one instance, thin layers, of very dense, hard, dark reddish, banded material. This in thin section closely resembles the banded, dense, red types forming the main rock mass. The two rock types, that is, the bright red, somewhat cherty-looking material which occurs in thin discontinuous layers and the ordinary banded measures, apparently grade into one another along their mutual boundaries. In detail these boundaries are minutely irregular with individual granules projecting from one type of rock into the other, and the whole boundary is a series of embayments and finger-like projections of one rock in the other. The individual brightly coloured, relatively coarse layers may extend for yards but always end. The number of such layers, in the general zone, varies from place to place, and individually they range in thickness from ½ to 6 inches.

Still higher in the section, in the zone between 60 and 70 feet above the base, the strata are banded. They are chiefly purple and red, but with some zones of black and with layers of the bright red, granular material with the semi-conchoidal fracture and slightly vitreous aspect. The black layers are very dense; in part they have a shale-like parting, in part they are more massive, very dark grey and dense, though a lens reveals minute, red bodies. The rock has a banded appearance due to the arrangement along parallel planes of lenticular black bodies 0·05 to 0·03 inches long. These show shining faces, and effervesce in acid. This dark rock in thin section was found to be composed of a matrix of magnetite holding close-set, colourless grains often ovoid in outline, mainly of carbonate, but which in one band-like area were of microcrystalline

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silica. In another band-like area, the magnetite was in great excess. The rounded grains of carbonate in part extinguish simultaneously over large areas as though each grain were part of a larger body.

The associated red strata are banded in shades of dark purple. The alternating bands vary in width from a mere film up to one-quarter of an inch and in part have a striped appearance due to the presence of dark streaks rich in iron oxide. The alternate bands vary in texture from dense to minutely granular and are composed of red granules for the most part just distinguishable with a lens, set in a darker matrix. The rock also carries small glistening faces of carbonate. A specimen of a coarser variety was seen in thin section to be composed largely of iron oxide and transparent granules averaging about 1 mm. in diameter. The granules are of very finely granular silica, mostly red stained, and holding variable amounts of dust-like iron oxide. In parts of the section, the iron oxide, chiefly magnetite, is so abundant that it appears like a matrix holding the colourless grains. In other places, the magnetite grains are more widely spaced and have the size and shape of the granules. A slight amount of green mineral is present in some of the granules.

The red, finely granular, slightly vitreous-looking material present in these red and black-zoned strata forms highly irregular lenses and strips. Some are several feet long, brilliant red, and composed of minute ellipsoidal and occasional sharply rectangular, red granules varying in size up to 0·03 inches and closely set in a dark, dense base that contains carbonate. The borders of some of these layers are banded red and faintly reddish, almost black. The layers have wavy outlines, individual layers swelling, thinning, and terminating. The dark parts seem to be of the same materials as the lighter coloured parts but are much richer in iron oxide. A sample of a red part of one layer examined in thin section was found to be composed of granules, set in a colourless matrix of silica, that in part exhibits radiating and sheaf-like forms. The granules are mainly elliptical and vary greatly in size; most are opaque and wholly red in reflected light or with dust-like grains and aggregates either distributed through the granules or forming a partial rim. Some granules, red stained, are transparent and composed of exceedingly fine-grained silica. Individuals are present affording all gradations between granules wholly dense and others wholly clear save for included dust-like matter. Carbonate occurs in various areas, in rhombs and irregular grains developed without regard to the general structure. One exceptionally large granule was composed of about one hundred small granules set in a granular carbonate matrix.

Red-weathering strata, in part dark grey or black where unweathered and in general resembling the measures of the lower 70 feet, extend upwards in the section. Their total thickness is certainly 125 feet and may be as much as 175 feet, if, as is probable, the iron-formation everywhere in this rather limited area in the north part of Innetalling island has a uniform total thickness of 450 feet. Unfortunately in the few places where the whole iron-formation lies above sea-level and the position of the base is clearly indicated, the middle part of the formation is concealed and it is not possible directly to determine the thickness of the lower member. The highly ferruginous zone at the top of the Lower Horizon is exposed in various parts of the northern sections 180 feet below the top of the formation; it is 200 feet below the top in the southern sections. Assuming that the total thickness of the iron-formation remains constant at about 450 feet and that the top of the ferruginous zone marks everywhere an equivalent horizon, then, as displayed along the outcrop of the western band in the north, the lower, fine-grained, chiefly red strata have a thickness of 175 feet and extend upwards to an horizon 90 feet below the top

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of the Lower Division. They are there succeeded by a 15-foot zone of strata banded purple and dark reddish, nearly black, which are finely granular and rich in iron oxides. This zone resembles the upper ferruginous horizon, but has a lower content of iron. Above this zone for a thickness of 50 feet, the strata as shown in several sections in the northern part of the western band are chiefly red with layers and zones of dark grey. The red beds are in part ferruginous with occasional beds of a high iron content. These measures in character are intermediate between the overlying ferruginous zone and the denser, less ferruginous beds of the lower part of the formation.

Towards the north end of the west band, a well-defined ferruginous zone commences at an horizon assumed to be about 240 feet above the base and extends upwards for 27 feet to the top of the Lower Division. The strata in this zone are markedly banded and this appearance is emphasized by the presence of much of the red, somewhat cherty-looking material in flattened lenses arranged as though they were portions of disrupted or partly replaced, thin, irregular layers that swelled and pinched in thicknesses from one foot to less than an inch. In places such material is more abundant than in others. On the whole it is estimated to occupy at least 10 per cent of the total volume. The associated ferruginous strata are in part black, being a fine-grained aggregate of minute granules of magnetite and red-coloured material. The individual layers are mainly massive and unbanded. Some are so rich in magnetite that the granules are no longer apparent. Layers are present exhibiting characters ranging from those of the dark, magnetite-rich beds to others which are red, low in magnetite, and very clearly exhibit the granular texture. Zones are present, also, which include layers of very dense, almost argillaceous-looking material, other dark greenish layers, and still others finely granular in texture approximating in character the "blocky" type.

The highly ferruginous zone at the top of the Lower Division is traceable southward along the western band for about 4 miles until it sinks below the waters of the tidal lake, and it is visible at intervals along the course of the eastern band. In places the relations holding between the ferruginous strata and the interrupted, thin, red, irregular, somewhat chert-like layers, seem to indicate that these layers at one time were continuous, but since have been partly replaced. At one exposure what appears originally to have been a 6-inch layer of the red rock is now represented by larger and smaller bodies of various shapes, but so disposed as to clearly define what seems to have been the two bounding planes of a uniformly thick and presumably solid layer. The fragment-like remains of this once continuous layer are now embedded in finely granular ferruginous rock minutely streaked and lined in black. This lining is parallel to the bedding in the main body of the rock, but in the fragmentary layer it conforms to the curving, irregular outlines of the fragments, and where the granular ferruginous matter crosses the band in narrow strip-like areas the lining is parallel to the sides of these strips. Depending on the direction of the strips, it may even follow planes at right angles to the normal bedding planes. Considering that the ferruginous country rock is composed so largely of granules and that these presumably received their outlines when the rocks first formed, it seems probable that the replacement of the red, somewhat vitreous layers, if such a replacement has happened, took place while the strata were still forming and prior to their final consolidation.

Upper Division

Wherever the top of the ferruginous member at the summit of the Lower Division is exposed it is sharply terminated and is succeeded by dark, slaty beds, in part hard and splintery. A few feet up, these become reddish and in

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some places at least, at an horizon 35 feet above the base there is a zone containing many irregular layers of the red, somewhat chert-like rock and a few beds of the grey, granular, irregularly bedded type.

The slaty strata are succeeded upwards by a band of the grey, granular rock variety. The base of this band was nowhere seen, but its summit is visible in many places at an horizon 90 to 95 feet above the base of the Upper Division. The greatest exposed thickness of this band is 35 feet. The rock composing it is dark grey and varies in grain. The individual grains, when large enough to be distinguished by the aid of a lens, are reddish, grey or black. Occasionally they are rounded, but most seem irregular of outline. Small grains of carbonate are present, the amount varying from spot to spot. There are some very dark irregular streaks and areas due to the abundance of finely granular magnetite. At some localities the mass holds many partings of nearly black, dense, slaty material. In some exposures the whole bank is interleaved with irregular, discontinuous layers, lenses, and streaks of the brilliant red, chert-like material. This red material is composed of small red granules, many with a dark centre of magnetite, closely set in a paler matrix. In thin section, the large, close-set granules were seen to be composed of very finely but distinctly crystalline silica, stained reddish, and, in some cases, with groups of small magnetite grains generally centrally disposed. The granules are turbid, varying in this respect from faintly turbid to almost opaque. The turbidity is apparently the cause of the red colour. The sparsely developed matrix is a rather coarse quartz mosaic.

The relations of this red material to the normal rock are intricate. In general the red layers are sharply outlined, but in places their boundaries are embayed and narrow projections of the red seem at their extremities to be represented by small detached masses, the outermost of which in size are only minute grains. One layer of the red material several inches thick was observed into which the grey, granular rock projected as a narrow, straight, vein-like body an eighth of an inch wide; towards the middle of the red layer this vein expanded into a body of irregular outline, one-half inch in diameter and with numerous red granules throughout. In some parts of the rock mass, the red material instead of forming numerous definite layers is represented only by small, irregular bodies not systematically arranged. The phenomena thus referred to seem to indicate that the red material has suffered replacement by the grey.

The bank of grey, granular rock is succeeded upwards by a zone varying in thickness, in different sections, between 5 feet and 10 feet and consisting of dark, dense strata, in part slaty-like, in part hard and splintery. These beds characteristically weather a dark brown in a sharply defined outer zone. At one locality this weathered zone holds many layers, etc., of the red, somewhat chert-like material and beds of the dark strata are crowded with minute octahedra and specks of magnetite.

The dark horizon is succeeded upwards by 30 feet of the grey, granular rock type not distinctly bedded and holding numerous streaks of rusty and dark brown weathering matter. The main rock is a very dark grey, with a sheen due to the great quantity of minute specks of magnetite. These lie in a finely granular, crystalline ground free from carbonate. The strata are hard, massive, and not distinctly bedded, but parting in irregular layers. An example of this rock in thin section appears as a granular mass of magnetite and quartz. The quartz occurs in interlocking grains, varying in size but perhaps averaging 1 mm. The magnetite is less abundant and the individual grains mostly possess clean-cut crystal boundaries. In addition to these constituents there are large and small felted aggregates of a green mineral in thin plates.

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At the locality that shows abundant red, cherty-looking material in the underlying slaty zone, this blocky layer carries much of the same cherty-looking matter and the upper part of the bank has interbedded leaves and thin layers of dark strata resembling that of the next overlying horizon.

The grey granular bank just described is overlain by 20 feet of dense, dark strata. In several localities, the uppermost beds are unbanded and contain a carbonate. They have an outer, weathered, deep brown to almost black zone, whereas the fresh interior is a deep chocolate brown, very fine grained, and full of minute, brightly shining flakes irregularly disposed. Below this layer the strata are of purple, compact rock, in part almost dense, in part with a suggestion of granularity. They are ferruginous and in some cases display tiny specks of magnetite and minute red granules. A specimen of the upper dark beds, in thin section shows specks and small grains, some with crystal boundaries, of magnetite uniformly scattered through a turbid base apparently very largely formed of finely granular carbonate carrying innumerable thin plates of a green mineral. Individuals of this green mineral, according to the direction in which they are cut, appear either as ragged films or acicular forms.

These fine-grained beds are overlain by a band of the grey, granular rock type that forms the uppermost horizon of the iron-formation. It varies in thickness from 25 feet in the north to 50 feet in the south. The rock weathers reddish, but is dark greenish grey on fresh surfaces and is streaked, parted, and recessed by rusty-weathering material which in places perhaps equal in volume the more normal strata. Much of the rock weathers with a pitted surface due to the presence of grains and small aggregates, up to 0·25 inches or more in diameter, of this same rusty-weathering matter. The latter occurs in long strips, in places in bands or highly irregular, elongated lenticular bodies.

The normal rock on fresh surfaces is almost black, flecked with white, and possesses an irregular, semi-conchoidal fracture. With the aid of a lens it is possible to distinguish innumerable pale coloured, faintly greenish granules set in a darker matrix. In thin section the rock appears composed of very fine-grained but distinctly granular silica arranged in a coarse net-work whose meshes are oval, and irregular areas of comparatively coarse, slightly reddish, quartz mosaic containing a few shreds or wisps of green mineral. No iron oxide is visible. Presumably the oval and irregular areas represent large granules. A number of rhombs of calcite with pronounced zonal structure have developed without respect to the general structure of the rock.

The markedly rusty-weathering material, so abundant in the strata, is, on fresh surfaces, pale grey, crystalline, of medium grain, and has a faint vitreous lustre. In thin section it appears as a finely granular, interlocking aggregate of carbonate with occasional small grains of quartz and countless needle-like forms of a mineral resembling sillimanite.

At one locality where, as already noted, the underlying strata are somewhat abnormal and contain much of the red, somewhat chert-like material, the uppermost horizon also shows a development somewhat out of the ordinary. The lower part consists of irregular massive layers of rusty-weathering, very dark greyish rock minutely flecked with white. It is very dense, almost cherty, in appearance and bears grains and irregular aggregates up to one-half inch in diameter of clove-brown, finely crystalline carbonate. In thin section, this rock variety appears composed chiefly of silica, in part very finely granular, in part in small irregular areas, relatively coarse grained. Possibly the finer-grained matter represents large granules whose boundaries are not distinguishable. A small amount of turbid carbonate is present partly in irregular, partly in crystal forms.

The upper part of this stratum is in part of rock like that of the lower part, and in part is denser, duller-looking, and lacks the areas of carbonate.

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TUKARAK ISLAND AREA

On Tukarak island the eastern band of the iron-formation is for the most part drift covered, but at two localities outcrops are more numerous and it is evident that the general expression of the formation is different from that of the already described areas.

At one locality, one mile south of Laddie harbour, the formation is 365 feet thick. The lower part, 245 feet thick, is only partly exposed and so far as seen is composed of very fine-grained strata, chiefly banded purple and dark grey or black. Towards the base there are more thinly banded measures of red, green, and dark grey colours and with zones in which are numerous irregular layers of the red, somewhat chert-like material.

These banded rocks are succeeded upwards by about 15 feet of dense, black, slate-like strata with a thin, outer, brown-weathered zone. Above this for 30 feet in the rock section, the dark, dense rocks are interbedded with ferruginous layers which upwards increase in thickness and frequency and finally for a thickness of 10 feet between horizons 290 feet and 300 feet above the base of the formation, the strata are all ferruginous. Above this, through an interval of 65 feet to the top of the iron-formation, the strata are wholly concealed.

The ferruginous rocks are banded dark red, purple, and nearly black. Individual layers are finely granular, not unlike a fine, even-grained sandstone; they are compact, unbanded, and have a sheen due to abundant, minute, scaly particles of brilliant lustre. The variations in colour are largely due to the variations from layer to layer in the amount present of finely granular magnetite. In thin section the rock is seen to be an even-grained aggregate chiefly of clear grains of quartz, orthoclase, microcline, and plagioclase feldspar, and of shapeless aggregates of hematite and magnetite which with a green mineral act as a matrix in which the colourless grains lie embedded. The grains of quartz and feldspar apparently are of clastic origin and are rounded or irregularly rectangular of outline. Most of them have narrow borders of the green mineral which seems to be penetrating the quartz and feldspar grains and in some cases follows cracks across them. A complete series of examples exist, from clear grains having the narrowest of green rims to others composed nearly entirely of the green mineral. It seems reasonably certain that the green mineral has partly replaced the quartz and feldspar.

Six miles north of the above-described locality or 4 miles north of Laddie harbour, the iron-formation is partly exposed and has a thickness of 370 feet. The lowermost strata for a thickness of 35 feet are concealed. Above this for 70 feet to an horizon 105 feet above the base of the formation, the strata possess a marked banding. To near the top of the 70-foot interval the measures occur in thin beds and layers an inch or less thick and variously coloured black, grey, dark and light reddish purple, and green. The strata are all fine grained and slate-like. One variety in thin layers of an eighth of an inch and less is chiefly dark greenish, but partly black and pale grey. The different layers are not continuous, many of them being very short, lens-like. The whole is very fine grained and hard. In thin section the rock is seen to be composed of close-set grains of quartz, orthoclase, microcline, and plagioclase; abundant carbonate in minute grains and larger irregular forms appears to be replacing the quartz and feldspar. In addition there is considerable magnetite and a small amount of green mineral. The rock is banded, the banding being made evident by the concentration of the magnetite along narow zones. The rock is essentially a clastic.

Above these fine-grained banded strata, for a thickness of 10 feet up to an horizon 115 feet above the base of the formation, the strata are almost

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dense and purple. They include ferruginous layers and also many irregular layers of dark coloured, somewhat cherty-looking material. Above this zone, through a thickness of 15 feet up to the 130-foot horizon, the rock is chiefly of the bright red, chert-like matter which forms irregular layers and lenticular masses as thick as 6 inches. These occur in bright red, dense yet faintly granular, slaty beds containing much hematite.

Upwards in the section for 75 feet to the 205-foot horizon, the strata are very fine grained, banded in various shades of purple, with thin films and bands of grey finely granular material. Along their parting planes the rocks mostly exhibit a faint sheen due to abundant, brightly reflecting, presumably scaly forms.

The reddish, purple and grey-banded strata are overlain by dense, compact, black strata carrying, irregularly arranged, minute scaly forms and weathering to form an outer brown zone. Upwards for nearly 50 feet the strata are poorly exposed, but in this interval there is one exposure of beds of black, faintly purple-tinged rocks which are very dense and moderately soft. They are grey lined in thin zones and have slate-like partings possessing a faint sheen from the abundance of minute scaly forms.

Between horizons 250 feet and 305 feet above the base of the formation, the measures are banded in reddish, purplish, and purplish-grey shades. In the lower part of this 55-foot interval the alternate bands are very narrow and some of these are largely of finely granular, grey material, presumably of clastic grains, forming short overlapping layers. Upwards the grey bands decrease in amount, the rocks gradually assume a more prominent granular appearance, and towards the top many layers are highly ferruginous.

The succeeding strata for a thickness of 35 feet to an horizon 340 feet above the base, so far as they are exposed, are highly ferruginous and largely dark reddish. They have irregular fractures, feel rough, and look minutely granular. Fresh surfaces have a faint sheen. Examined with a lens the rocks have the appearance of a fine, even-grained sandstone. Some of the beds are less ferruginous than others, are banded in lighter colours, and are denser and more argillaceous in general appearance. All the layers or bands vary in thickness along the strike.

A thin section of one of the coarser phases shows the rock to be an aggregate of rounded and irregular grains of quartz, orthoclase, microcline, and plagioclase feldspar, specks and irregular grains of iron oxide, and aggregates of green mineral. The iron oxide appears as a matrix holding the colourless quartz and feldspar individuals, but though the iron oxide in part may play the part of a host, yet by reflected light this material appears in part as rounded aggregates corresponding in shape and size to the colourless grains. There are also examples which show a complete gradation from quartz or feldspar grains encircled with a very narrow rim of hematite to other grain-like forms either solely of hematite or with a small, remnant-like core of quartz or feldspar. Apparently the iron oxide has in part replaced the clastic grains. Magnetite occurs as grains bordered by hematite, but most of the dark oxide occurs dust-like as small specks and small formless grains irregularly distributed through the hematite. The green mineral forms individuals in shape and size like those of quartz and feldspar, but occurs partly in irregular aggregates, and these together with the more regularly outlined forms are either a felted mass or an assemblage of bladed forms.

Above the exposures of ferruginous strata, the rocks are concealed for a thickness of 20 feet up to an horizon 360 feet above the base or 10 feet below the top of the formation, where a thickness of 5 feet of the grey granular type is exposed. Upwards the strata are concealed to the top of the formation. The

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grey variety in thin section is seen to consist of faintly yellowish, in part turbid granules lying in a clear, quartz mosaic. The clearer granules are composed of finely granular silica, in many cases with a relatively coarse-grained central part. The turbid granules in part owe their turbidity to dust-like magnetite, but mainly to turbid carbonate which in the aggregate is very abundant. The carbonate grains for the most part are small rhombs with an occasional one much larger than usual. Some of the granules are wholly carbonate and the same mineral also occurs in the matrix. A few shreds of green mineral are present.

Origin

CONDITIONS OF DEPOSITION

The iron-formation, as the previous descriptions indicate, is a bedded formation, varying in thickness, so far as known, between 300 feet and 450 feet and exhibiting no evidence of having been subjected to either contact or regional metamorphism. A large part of the formation is composed of dense, red, somewhat slate-like strata made up of very finely granular quartz and carbonate. These constituents are in varying proportions in different beds and bands and are accompanied by a small amount of minute clastic grains of quartz and feldspar. The red colour is due to dust-like hematite frequently so abundant as to obscure the other rock constituents. These dense red types in places grade into finely granular, red, purple, and black, richly ferruginous rocks which in addition to hematite and magnetite are largely composed of finely granular quartz that in part forms the matrix of the rocks and in part forms distinct rounded aggregates or granules. A third rock type is dark grey or black, usually slate-like, banded, and dense. This type commonly carries considerable fine-grained, detrital quartz and feldspar and is composed of ferruginous carbonate and finely divided quartz in various proportions. A fourth rock type, unlike the preceding varieties, is not distinctly bedded nor banded, is grey of colour, finely granular, and composed chiefly of very fine-grained quartz that occurs in minute granules and as a matrix around these forms. A fifth rock type is highly ferruginous, bedded and banded, resembles fine, even-grained sandstones, and is chiefly composed of minute clastic quartz and feldspar grains lying in a base of granular hematite and magnetite. A sixth rock type is greenish, purple or red, possesses a slightly vitreous lustre and a semi-conchoidal fracture. It superficially resembles chert or jasper, but is composed of minute granules, largely of quartz, set in a dense, siliceous matrix. These jaspery and chert-like rocks do not form homogeneous zones, but occur as irregular discontinuous layers in the ferruginous horizons and, in places, in zones of the compact, grey, granule-bearing type.

A striking feature of the formation is its banded or bedded character. The individual bands vary from mere films to essentially homogeneous zones 20 or more feet thick, but the great bulk of the layers range in thickness from a small fraction of an inch to several inches. The individual layers differ from one another in colour and texture and these differences seem to correspond to a still wider range in mineral and, presumably, ultimate composition. Some sixty thin sections were examined under the microscope and the results of this examination seem to indicate that only by a minute examination of the strata layer by layer, could a proper conception be obtained of the number, kinds, and relative proportions of the different rock varieties present. Independent of the exact mineralogical characters of the individual layers, one important general feature was plainly evident by macroscopic examination in the field, namely, that each individual layer usually grades into one or both of the bounding layers.

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In some cases this passage is gradual through a considerable proportion of the thickness of the layers, whereas in other instances the change is almost abrupt.

An analogous feature on a larger scale is also characteristic of the lower part of the formation where throughout the several hundred feet of strata composing what has been termed the Lower Division, the general character varies from zone to zone. Successive zones merge into one another as a result of the interbedding of different rock varieties and of slow changes in the lithological characters of the individual layers accompanied by gradual changes in the relative proportions of the numbers and sizes of the various rock varieties. In the Upper Division, on the other hand, the strata of each zone are lithologically distinct. The rocks of one zone do not grade into those of adjoining zones. Their contacts are abrupt, though in some instances at the junction of the zones the contrasting rocks are interbedded.

The zonal distribution of the strata is indicated in the folowing tabular statement. In the case of the zones described in this table as being composed of "red and grey, dense" rocks, the red and the grey measures, respectively, form distinct zones which in general grade into one another by interbedding.

Lithological units	Thickness in feet			
	1	2	3	4
Grey, granule-bearing	.....	.....	25 to 50	.....
Dark, dense	40	24	20	.....
Grey, granule-bearing	25	21	30	.....
Dark, dense	.....	.....	5	.....
Grey, granule-bearing	.....	.....	45	.....
Dark and red, dense	50	25	50	.....
Ferruginous, granule-bearing	50	.....	30	.....
Red and grey, dense	50	45	50	.....
Ferruginous, granule-bearing	.....	10	15	.....
Red and grey, dense	.....	15	130	.....
Ferruginous, granule-bearing	.....	10	.....	25
Red and grey, dense	.....	80	.....	.....
Grey, granule-bearing	.....	26	10	.....
Red and grey, dense	.....	66	30	105

Locality No. 1. Kasegalik Lake area; lower strata not exposed.
Locality No. 2. Kipalu Inlet area, south end.
Locality No. 3. Innetalling Island area.
Locality No. 4. Tukarak Island area, northern section; lower part only.

Microscopic examination indicates in unmistakable fashion that all the strata have been subjected to processes of alteration, but these processes seem to have consisted in the main of the replacement of one mineral by another without completely obliterating the original rock textures and structures. The rocks examined are with scarcely an exception, either fine-grained, banded, but otherwise formless aggregates frequently carrying clastic grains, or else they present definite evidence of having been composed of minute granules lying in a distinct matrix. Several thin sections showed that siliceous rocks of the granule-bearing type had been partly transformed into a finely granular quartz aggregate bearing only remnants of the granules. Other thin sections showed carbonate to have replaced original constituents and to have partly destroyed the original textures and structures; but this destruction was never complete. It does not seem probable that many, if any, of the carbonate-rich layers originated in this fashion, for the secondary carbonate always appeared

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to be mineralogically distinct from the more abundant rock-forming variety. Single thin sections and suites of thin sections afforded examples of long series that seemed to indicate all stages in the replacement of one mineral by another, but no examples were observed of the transformation of rock varieties bearing clastic grains into dense, structureless rocks or into granule-bearing types. Neither, except partly in two instances, were granule-bearing strata observed to graduate into structureless rocks. The absence of any such examples is considered ample proof that no wholesale transformation of the strata has taken place and that the present textures and structures are original. The fact that different rock varieties form definite zones traceable for long distances and in some cases of remarkably uniform thicknesses, is also evidence that on the whole the present rock structures and textures are original.

The iron-formation is indicated to be of sedimentary origin by the bedded nature of the whole formation, the zonal grouping of beds of allied lithological characters, the uniform manner in which individual zones extend for miles along the strike, the banded character of most of the zones and the accompanying variations in mineralogical and textural features from layer to layer, the natures of the apparently original textures and structures exhibited by the different rock varieties and by the presence of clastic grains of quartz and various kinds of feldspar. Except the clastic quartz and feldspar grains, no material of clearly detrital origin was noted, but it seems possible that some of the fine-grained beds may hold finely comminuted argillaceous matter. No tuffaceous material was anywhere recognized nor was there any indication of the former existence of any such materials. All observed characters agree in indicating that except for the relatively unimportant clastic matter, the iron-formation is of the nature of a precipitate produced under changing conditions. The nature and source of the original solutions and of the agents of precipitation, whether organic or inorganic, are not directly indicated.

Some of the general conditions governing the manner of deposition of the iron-formation may be deduced by considering the nature of the preceding and succeeding formations. Underlying the iron-formation is a very thick assemblage of impure limestones, fine-grained mostly calcareous sandstones, and mud rocks. They give evidence of having formed in standing water, and it is reasonable to believe that the basin was at least sufficiently extensive to include the areas of similar strata distributed at intervals for a length of 300 miles along the east coast of Hudson bay. The waters of this basin may have been fresh, but no evidence supporting such a conception was collected; it seems more probable that the waters were marine.

The formation immediately underlying the iron-formation is essentially a clean, even, and fine-grained quartz sand with a variable amount of carbonate that in part forms relatively wide bands in the quartzite. The contact of the quartzite with the overlying iron-formation is sharp. There is no evidence of an unconformity, no interbedding of the two classes of materials, and absolutely no signs of any grading of one into the other. The nature of the contact and the character of the two formations seem to indicate that deposition of the quartz sand was succeeded by a considerable interval of non-deposition during which the sand was reworked, shifted, and spread out by tidal or other currents. Deposition of materials may have proceeded continuously in other parts of the basin, but in this area in order to explain the abrupt succession of two such unlike formations, it seems necessary either to postulate an intervening period of non-deposition or to suppose that the precipitation of the thick iron-formation (300 to 450 feet) was abruptly commenced and was so rapidly accomplished that only a very small amount of clastic material was included in it. It seems probable that the area was continuously submerged

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while the iron-formation was being deposited, for the overlying basalts have a prominent ellipsoidal structure such as is not inconsistent with a belief that these flows were submarine. Furthermore, the strata of the iron-formation nowhere afforded any evidence of even a temporary emergence during their deposition. Interleaved with the basalt flows are thin, discontinuous layers of black, carbonaceous, shale-like strata, in all probability truly argillaceous. Their presence corroborates the general conception that the iron-formation was deposited in a basin, probably marine, during an interval when little or no coarsely clastic material was laid down, but when some argillaceous matter may have been deposited along with the iron-formation. The interval was apparently closed by the outpouring of basaltic flows accompanied by the deposition of dark muds.

The available direct evidence as given above seems to justify the conclusion that the iron-formation is primarily a sediment precipitated in an extensive marine basin, that precipitation was accomplished in some unknown way and that it took place under changing conditions. These conclusions are in part based on observations which indicate that certain rock textures and structures are original features which have been preserved despite the fact that various mineralogical substitutions may since have taken place. The nature of these mineralogical changes and their probable date are matters of prime importance in connexion not only with a discussion of the mode of origin of the iron-formation, but also in connexion with any discussion of the possible existence of iron ore deposits of economic importance.

PARAGNEISSES

The mineralogical constancy of the individual lithological zones composing the iron-formation is striking and significant. The iron-formation was examined over a considerable length of outcrop in four separate areas and in a single partial section in a fifth area. These areas are distributed within a district 40 miles long by 20 miles broad. Except in the northeast part of this area of 800 square miles, the iron-formation is clearly divisible into an Upper and Lower division each of which wherever developed has the same distinctive features. Furthermore, lithological units no thicker than 5 to 25 feet may be traced along the outcrops for upwards of 10 miles. In the northeastern part of the district it did not seem possible to divide the strata into two horizons respectively equivalent to those found elsewhere, but the strata of this area are divisible into a number of horizons, some only a few feet thick, traceable along the strike and possessing characters and thicknesses as uniform as the subdivisions of a normal sedimentary formation. Therefore, however greatly the strata may have been changed, the iron-formation is stratigraphically similar to more normal sedimentary groups. Even the highly ferruginous beds which might be assumed to be largely secondary, occur in each area at definite continuous horizons. Such a condition indicates that the present lithological characters are essentially original. Any mineralogical changes that may have taken place must have been almost contemporaneous with the first laying down of the beds, or else, if they occurred long afterwards, they must have been accomplished by agents operating with almost uniform effect through each lithologically distinct zone.

The clastic grains of quartz and feldspar are the only constituents that unquestionably are original. The uniform, clear, undecayed condition of the feldspar grains indicates that they are the product of a mechanical disintegration of an earlier rock. But it is not clear whether the granules of the granule-bearing rock types were at one time all composed of greenalite or some allied

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ferruginous compound, or whether some were of iron oxide, or of silica, or of carbonate, or of mixtures of various minerals. The thin sections alone give no certain indication of the original mineralogical composition of the granule-bearing rocks. There is, however, a considerable body of evidence indicating that the iron oxides are at least partly replacements both of the granules and of the matrix and of larger irregular forms of what once was a green mineral.

The non-clastic beds of the formation are composed of silica, carbonates, hematite, magnetite, and a green mineral or minerals thought to be in part, at least, greenalite. These minerals were observed to occur in so many combinations and proportions as to render it probable that there are layers composed of any one or of any two, three, four, or all five of these constituents in various proportions.

The very fine-grained strata so prevalent in the Lower Division were found in the few specimens microscopically examined to be exceedingly fine grained and composed chiefly of carbonate or perhaps, in some instances, carbonate and silica. Dark dense strata of the Upper Division are in some instances largely of finely granular carbonate that in some cases forms the matrix in which lie clastic quartz and feldspar grains. The carbonate in such and related examples has every appearance of being an original constituent. It is indicated to be ferruginous by its turbid appearance, the associated dust-like or very finely granular hematite or magnetite, or both, and by the characteristic yellowish and brownish, limonitic outer weathered zones of some of these rocks. Secondary carbonate was observed as vein-like aggregates or crystals in many thin sections.

The silica was observed to occur in three general ways. First, as fine-grained aggregates partly or wholly forming spherical, elliptical, and more irregular minute bodies or "granules." Second, as finely granular aggregates partly or wholly forming a matrix holding such granules. Third, rarely as granular aggregates holding only fragments and mere traces of granules as though the rock were undergoing a process of recrystallization. Though many layers were observed which bore a casual resemblance to dark chert or brilliant jasper, no undoubted example of chert or jasper was found. The chert-like and jasper-like layers invariably displayed perfectly preserved granules of varied composition in, apparently, unaltered siliceous matrices. In a number of examples the rocks consisted essentially of granules of silica in a granular matrix of the same material. In many thin sections granules composed almost entirely of silica were accompanied by others formed of greenalite, others of iron oxides, and yet others composed of any two or all three of these main constituents in various proportions. Phenomena to be referred to later seem to indicate with a reasonable degree of certainty that much if not all the iron oxide is secondary. The debatable point is whether all or nearly all the granules were once composed of a single mineral, greenalite or quartz, or whether some granules were originally of greenalite and others of quartz.

The granule-bearing rocks occur now with three main habits and form definite zones alternating with dense strata. In the Upper Division the granule-bearing strata form grey, nearly massive zones from a few feet up to 50 or more feet thick. These rocks are mainly composed of quartz and are relatively poor in greenalite and iron oxide. In the Lower Division similar rocks in different localities form one or two zones. A second general type of the granule-bearing rocks occurs in the Lower Division. It is highly ferruginous and occurs in groups of definite beds of varying textures and mineralogical composition. A third general type occurs in thin discontinuous layers. It is

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highly siliceous and usually red and jasper-like or grey and chert-like, but the resemblance to jasper or chert is only superficial. These discontinuous layers in some cases accompany the granule-bearing strata of the Upper Division and always occur with these rocks where developed in the Lower Division. The tabular statement on page 40 indicates the positions of the observed zones of the granule-bearing rocks in the generalized sections representing the various areas examined.

If the granule-bearing zones in the Upper Horizon were once composed of granules of greenalite lying in a quartz matrix, it is remarkable that now, wherever the strata are exposed in the areas examined, the granules are essentially of quartz. The area examined is considerable, consisting as it does of three outcrops of the iron-formation, each 10 miles or more long, and with the two most distant outcrops 35 miles apart. Eminent authorities have shown that lithologically essentially similar rocks in the Mesabi district, Minnesota, have developed from rocks whose granules once were solely or mainly composed of greenalite. Therefore, lacking evidence to the contrary, the analogous strata on Belcher islands also presumably once contained granules only of greenalite. In the Mesabi district the alteration of the greenalite rocks to the more purely siliceous rocks has been shown to be due to ordinary processes of weathering and circulating surface waters. The same general agents may have produced analogous changes in the rocks of Belcher islands, but there is some evidence that indicates that other transforming processes were also active.

In describing the strata frequent reference was made to thin, discontinous layers of rocks that superficially resemble chert and jasper. These rocks are in part bright red like jasper, in part of duller green and purple tones, and have a slightly vitreous lustre and splintery or semi-conchoidal fractures. Unlike jasper or chert, they are composed of granules lying in a fine-grained siliceous matrix. Thin layers of these occur occasionally in the dense strata of the Lower Division and are very abundant in the ferruginous zones, in some places representing 20 per cent of the rock volume. Similar layers also occur in some districts with the grey, granule-bearing zones of the Upper Division. In the detailed description of the strata it has been stated that in places these layers give evidence of having been partly replaced by the rocks in which they occur. Examples have been cited of layers which for an interval are represented by irregular bodies with curving outlines, so disposed as to indicate very clearly the former boundaries of the layers. An example was described where the enclosing strata, being lined and streaked parallel to the bedding, retains this structure where it lies between the fragments of the once continuous layer. The lining and streaking tend, however, to be parallel to the irregularly curving outlines of the fragments of the layer, and in places is parallel to planes at right angles to the bedding. The detached portions of the once continuous layers are not products of contemporary erosion, for they still lie in their original position, and their outlines are frequently highly irregular with curving tongue-like projections and deep embayments sometimes enlarging inwardly. All the observed facts indicate that these layers were unstable products of deposition subject as soon as formed to partial—perhaps in many cases complete—re-absorption of replacement.

Since the somewhat jasper-like and chert-like layers in all probability were absorbed or replaced as the strata were forming, it is not unlikely that other members, also, of the rock assemblage were subjected to transformations during, or immediately following, their deposition. Thus, even assuming that the granules of these rocks were originally largely or solely greenalite, it does not seem necessary to suppose that all or any alteration of such granules took place after the final consolidation of the iron-formation. It is concluded that

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the grey granule-bearing strata that form the prominent, continuous zones in the Upper Division and are uniformly deficient in greenalite and low in iron oxides, may have received their present mineral composition prior to the final consolidation of the iron-formation.

The mode of occurrence of greenalite has been partly referred to in the preceding discussion. The mineral occurs forming the whole of granules and also in shred-like forms in siliceous granules. It occurs, too, in irregular forms through the matrix and is abundant in many of the dense, non-granule-bearing rock varieties. In many cases the greenalite appears as though partly altered to or replaced by hematite or magnetite. In many cases individual areas of iron oxide have outlines precisely similar to those of aggregates and films of greenalite, as they occur in granules or in the matrix of the granule-bearing and dense rock varieties. Without doubt the greenalite has been replaced in a varying degree by iron oxides.

In many of the dense rocks, a green mineral is very abundant and is supposed to be greenalite. Possibly this mineral has been wrongly identified; it may be a hornblende. It occurs in matted masses, frequently with much carbonate. It also, in some rocks, forms coarser, granular bands enclosing clastic grains, or occurs in ragged grains and more regular plate-like individuals. Beds of these dense rocks rich in the green mineral may be recognized in places in the ferruginous zones of the Lower Division, interbedded with the granule-bearing rock types. In such interbedded layers, the green mineral appears to have been largely replaced by magnetite, still preserving the characteristic outlines of the individual aggregates of the green mineral.

The iron oxides almost invariably appear to be secondary. In some cases they are undoubtedly a direct product of weathering, as in the case of the outer, brownish, presumably limonitic, weathered zones of many of the carbonate-rich layers. But the hematite that gives the red colour to the bulk of the strata of the Lower Division does not seem to be a product of weathering confined to a shallow zone; instead, it seems to be an integral part of the rock which developed as each layer formed, or relatively soon thereafter. In the dense rocks, the hematite is for the most part dust-like. In some cases it is so abundant that thin sections of the rock are opaque. No evidence was observed that indicated whether such hematitic matter was originally deposited as such, or has been derived from ferruginous carbonate, or perhaps from original limonite.

In the coarser, granule-bearing rocks and in the dark grey, dense-grained types, magnetite is usually as abundant as hematite and often greatly preponderates. Some dark, granular beds are very largely magnetite. In the denser rocks the magnetite is disseminated dust-like, or as small, irregular grains, or as minute octahedra sometimes grouped in small aggregates. In the coarser, granule-bearing rocks, the magnetite may occur only as thin partial rims about or in irregular aggregates within the granules. Examples are common showing all gradations from forms such as these to others solidly composed of magnetite. Examples of what appear to be various stages in the replacement of greenalite and of the siliceous matrix in which the granules lie, are common. Hematite also shows the same phenomena. The relation of the hematite to the magnetite does not seem to be clearly indicated. It is not apparent, for instance, why in an outcrop of the ferruginous zone, some layers should be rich in both hematite and magnetite whereas other layers with a high magnetite content should hold little or no hematite. The view is held by most writers who have dealt with the subject, that in strata such as compose the iron-formation, the magnetite content is not original but has been derived from previously existing hematite or limonite or other iron-bearing minerals. Assuming this view to be correct and considering the frequent intimate association of the

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magnetite with hematite, and that both minerals hold the same relations to the other rock constituents, it seems necessary to conclude that the magnetite was mainly or solely derived from hematite. The hematite may have been derived from limonite in whole or in part, but in either case most if not all of the iron oxide appears to be secondary in nature, to have replaced other minerals. There is no available direct proof that the iron oxide did not develop long after the laying down and general consolidation of the iron-formation, but certain considerations indicate this could not have happened and that the iron oxide developed at a very early date.

The iron-formation is overlain by basaltic flows with thin, discontinuous shale partings. Sills of diabase, mineralogically similar to the basalt, intrude the iron-formation and underlying strata. These sills are not older than the flows. They may be of about the same age or considerably younger. In any case the iron-formation appears to have been sealed below a series of volcanic flows which, apparently, were submarine, and formed immediately after the deposition of the iron-formation. So long as the iron-formation remained buried beneath the overlying basaltic cover, which may have been augmented by considerable thicknesses of younger formations since entirely removed, it is scarcely possible that any notable formation of iron oxides could have taken place. If any limonite or hematite had formed previously it is conceivable that during the volcanic period some or much of it might change to magnetite. Such a change might also take place while the iron-formation remained covered or as long as any part of the ferruginous portions were deeply buried. There is no evidence of the strata having been affected by more than one general period of igneous activity. There is evidence of only one period of dynamic stress, namely, that interval when the strata were thrown into the broad, open folds now so clearly revealed. Subsequently erosion uncovered the iron-formation along the axes of the major anticlines. Since then no recognized process capable of producing magnetite has been operative at or near the surface. It seems, therefore, that the magnetite so abundantly developed must have formed while the strata were deeply buried, or still earlier.

The hematite so abundantly associated with the magnetite might be conceived as being secondary after magnetite, to have formed from it by the action of normal weathering agencies and surface waters after the strata were exposed by erosion. Some small portion may have been produced in this fashion, but it is improbable that the great bulk could have so formed. At present the iron-formation outcrops as narrow bands on the slopes or at the foot of basalt-capped ridges beneath which the measures dip. The exposed width of the iron-formation is rarely more than 150 yards, and this narrow outcrop very nearly expresses the width of the catchment basin for surface water, some portion of which might find its way underground along the strata of the iron-formation. At present, therefore, the amount of water that finds its way underground is insignificant, and the rocks at the surface—save for an oxidized film and the thin limonitic outer zone of some of the carbonate beds—are unweathered. Past climatic conditions may have been more conducive to surface weathering, but there is nothing to indicate that the present land forms are descendants of others that would have afforded larger water sheds to supply surface waters to the outcrops of the iron-formation. It is almost certain that the iron-formation was never exposed except as a narrow selvage along basalt-capped slopes. It thus seems that the conditions always were such that only a very insignificant amount of surface water was available to find its way underground through the iron-formation. It also seems fairly certain that, even granting a large supply of surface water, the underground circulation would not be vigorous, for the iron-formation everywhere dips downwards

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under an impervious cover consisting of a diabase sill overlain by basaltic flows interleaved with thin, discontinuous beds of shale. Furthermore, the rocks of the iron-formation are not now, and give no indication of ever having been, permeable to water except along parting planes.

Thus various independent lines of reasoning unite in indicating that the present content of iron oxides is not a product of superficial changes that took place after the iron-formation was uncovered by erosion, but, instead, resulted from processes in action at the time of deposition of the beds or shortly thereafter.

The foregoing account is mainly directed to offering explanations of various secondary characters of the strata. It does not seem that any facts were observed that definitely indicate what was the ultimate source of the nonclastic content of the iron-formation, how it was transported, or how its deposition was brought about. It may be, as Leith has suggested,[1] "that the essential requisite for the deposition of the iron-formation . . . was the event of great masses of basic lavas carrying excess of iron salts, contributing the iron salts in unusual amounts to the shallow waters, which disposed of them as best they could while handling the ordinary fragmental and chemical sediments." On the other hand Grout and Broderick,[2] in discussing the origin of the iron-formation of the Mesabi district make statements that seem equally applicable to the iron-formation of Belcher islands. These authors state that in the strata "there are hundreds of alternations. . . . Rhythmic sedimentation is in some cases due to a rhythmic supply of different materials. . . . If the material had been derived from volcanic sources . . . it seems improbable that these supplies would alternate as many times as the sediments indicate. It is unlikely that there were so many successive flows. Volcanic rhythms should produce alternations on a large scale. Furthermore, climatic rhythms are also larger features. The detailed alternation of beds from ⅛-inch to 6 inches thick is more likely attributable to seasonal or other occasional changes in conditions. These changes would affect a chemically depositing sediment only if in shallow water." As regards the nature of the solutions contributing the materials to these shallow waters, these same authors write: "The solution of silica may have been facilitated by the presence of alkalies; that of iron would be more likely in the presence of acids. If carbonate minerals were more abundant (as in some other ranges) an alkaline bi-carbonate solution might be suggested as the most probable combined solvent. This kind of solution is known to have had an igneous origin in some places."

[1]Leith, C. K., "An Algonkian Basin in Hudson Bay, etc.," Econ. Geol., vol. 5, p. 243, 1910.

[2]Grout, F. F., and Broderick, T. M., "The Magnetite Deposits of the Eastern Mesabi Range, Minnesota," Minn. Geol. Surv., Bull. No. 17, pp. 40-47, 1919.

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CHAPTER IV

ECONOMIC GEOLOGY

Iron-Formation Occurrences

The most westerly investigated outcrops of the iron-formation on Belcher islands occur on Flaherty island (Figure 3) in a band that is probably nowhere more than 500 yards wide. This band runs southerly from the northeast shore of the island to and along the east side of Kasegalik lake. Only the south end of this band was examined, but iron-formation has been reported to occur on the northeast coast, and distant views from near the head of Kasegalik lake unmistakably indicated that the strata continue northward along a nearly straight course probably to the reported outcrops on the northeast shore. The length of this band is 16 miles or more.

The northern part, so far as known, is largely drift covered, but in the last 7 miles to the south, commencing about opposite the head of Kasegalik lake, outcrops are not so rare. Finally, along the sides of a narrow easterly-intruding bay and for a mile south of this, the strata are comparatively well exposed. Along the east side of the lake the land rises quickly, in places precipitously, for about 200 feet to the edge of an upland. This upland is in part fairly level, in part much broken, and extends easterly to the shores of Kipalu inlet, or in the north to the northeast coast of Flaherty island. It is composed of the volcanic rocks, from beneath which on the west side the iron-formation outcrops along the slopes facing Kasegalik lake and along the sides of the valley that runs northward from the head of the lake. On the east side of the upland the strata reappear on the west shore of Kipalu inlet. The strata are nearly flat-lying, but on the whole slope gently to the east on the Kasegalik Lake slopes. The general structure is clearly expressed along the shores of the narrow, easterly-extending bay of the lake already referred to and along the low valley which extends east from the head of this bay to the shores of Kipalu inlet. In this stretch of about 2 miles the iron-formation is continuously exposed along the lower slopes up to the foot of cliffs of the overlying volcanics. At the west entrance, the contact of the iron-formation with the cover of volcanic rocks lies about 220 feet above sea-level. Eastward it sinks to as low an elevation as 60 feet and then rises to a height of 180 feet on the slopes facing Kipalu inlet. Along this line of section the beds, therefore, lie in a very shallow trough and doubtless this is the general structure of the whole of the upland area that lies between the valley of Kasegalik lake and Kipalu inlet and extends southward for some 60 miles from the northeast coast of Flaherty island to the entrance of Kipalu inlet. But minor undulations affecting the strata and a general southerly slope of the whole, cause the iron-formation to sink below lake level a short distance south of the above-mentioned narrow bay. It is not known whether farther south the iron-formation again rises above the lake level. For several miles at least, the volcanics outcrop along the shore and 20 miles to the south they were seen again rising directly from the water-level. If anywhere in this interval the iron-formation does come to the surface the probabilities are that only the upper part rises above the water-level and does not remain long exposed.

On the east side of the trough, that is along the western side of Kipalu inlet, the iron-formation outcrops at intervals for 35 miles to near the south entrance to the inlet. In places only the upper beds of the iron-formation

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rise above sea-level for distances of a few hundred yards, but at several places the whole formation may lie above sea-level though it is almost wholly covered by drift. At one locality in the south the strata dip at an angle of 70 degrees. Northward the beds are less steeply inclined and near the head of the inlet where exposed for the last time on the west shore, they dip gently westward.

The iron-formation undoubtedly underlies all of the ridge of volcanics between Kasegalik Lake valley and Kipalu inlet. In places this ridge is only half a mile wide, but in the north it is perhaps 10 miles broad. This ridge is estimated to occupy 125 square miles and consists of volcanic rocks resting on and concealing the iron-formation which, as already explained, is only intermittently exposed along the eastern and western sides. These volcanic rocks are in places at least 200 feet thick and in some localities are presumably much thicker.

Nowhere along the edges of this area is the full thickness of the iron-formation known to be exposed. Either the lower part lies below sea- or lake-level or it is concealed by drift. In the north, the upper part is well exposed along the east shore of Kipalu inlet, along the sides of the short depression that runs west from the inlet to Kasegalik lake, and for short distances north and south along the lake. In all, the upper part of the formation is clearly exposed over a length of outcrop of about 5 miles and everywhere has the same general expression. The upper 120 feet to 150 feet consists of three members of which the upper and lower give no indication whatever of grading into or carrying iron ore-bodies. The middle member, about 25 feet thick, is a finely granular rock type such as in the Mesabi iron range is believed to have been in places altered into iron ores. It is essentially what is called taconite or ferruginous chert. It is everywhere a greyish, highly siliceous rock and is not now high in iron whatever its original composition may have been.

At an horizon 120 feet to 150 feet below the summit of the formation lies a ferruginous zone at least 40 or 50 feet thick. On the Kasegalik Lake side this is the lowest stratum exposed, the remaining lower part of the formation being either drift-covered or below lake-level. On the Kipalu Inlet side, about 60 feet of strata appear from beneath the ferruginous zone. These lower beds are fine grained and give no indication of grading into iron ore. The ferruginous zone is exposed at intervals along Kipalu inlet for 2,400 yards. It lies below sea-level along the depression leading west to the bay on Kasegalik lake, but reappears on the south side of this bay and is exposed at intervals for 2,500 yards. It does not outcrop on the north side of the bay, being beneath lake-level or else drift covered. North of the mouth of the bay, it outcrops at wide intervals over a length of about 2 miles. Wherever it appears, the ferruginous zone has the same general character. It is composed of distinct beds, some black and largely of magnetite, others of varying shades of red and purple that carry both magnetite and hematite in various proportions and amounts. Some of the layers are very fine grained, but most are distinctly granular and resemble types such as yield ore-bodies in the Mesabi district. Interleaved with these measures are thin, discontinuous, irregular layers with a very low iron content and so abundant that in faces 15 to 20 feet thick, these form one-fifth of the total volume.

Four samples of different thicknesses of the ferruginous zone were taken and submitted to the Mines Branch for analysis. The results obtained are given in the following table. Analysis No. 1 is of a sample representing a thickness of 2 feet of black, magnetite-rich beds at the top of the ferruginous zone. Analysis No. 2 is of a sample from a thickness of 11 feet immediately below the black, 2-foot layer, both being from exposures on the shores of

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Kipalu inlet, on mining location No. 13. Analysis No. 3 represents a thickness of 12 feet of the strata on the same mining location, commencing 6 feet below the top of the zone and extending downwards. Analysis No. 4 represents a thickness of 15 feet of the strata on mining location No. 20, Kasegalik lake, 20 feet below the top of the zone and extending downwards.

	1	2	3	4
Fe_2O_3	41·41	42·30	43·50	45·10
FeO	29·92	19·74	11·12	4·95
Metallic iron	52·26	44·96	39·10	35·42
SiO_2	23·96	32·52	38·60	46·48
CaO	0·36	0·40	0·64	0·34
MgO	1·00	1·54	1·61	1·37
Mn	0·64	0·64	0·34	0·24
TiO_2	0·04	0·10	0·08	0·08
S	0·104	0·048	0·012	0·012
P	0·093	0·072	0·060	0·039

The material represented by analysis No. 1 is exceptional since it occurs only sporadically at the top of the ferruginous zone. The beds represented by the remaining three analyses are not commercial iron ore, for not only is the iron content low, ranging from 35 per cent to 45 per cent, but silica is very high, varying between 46 per cent and 32 per cent. It would be possible to improve the grade by removing the more highly siliceous layers by hand-picking, but though this in the case of the 11 feet of strata represented by analysis No. 2 might increase the iron content from about 45 per cent to 54 per cent, it would not reduce the silica content by more than 12 per cent, from 32·5 per cent to 20 per cent. It is questionable if it would be possible to remove the siliceous layers except at a prohibitive cost. These layers are discontinuous, vary in thickness from a fraction of an inch up to 6 inches, are tightly welded to the enclosing strata, and in places constitute as much as one-fifth of the total volume.

This ferruginous zone, however it may have formed, now appears as a continuous layer. Its ferruginous character is not accidental, but is due to the peculiar mineralogical and textural characters of the strata. These characters are not shared by the bulk of the associated strata, which give no indications of passing into ore. Any ore deposits that may exist must, in all probability, occur in connexion with this ferruginous zone or with any similar zones that may occur in the underlying part, or in the overlying part, as in the case of the 25-foot grey layer already mentioned.

The next band of iron-formation to the east outcrops on the east side of Kipalu inlet, Flaherty island (Figure 3). Commencing on the shore of the tidal basin at the head of the inlet, the band runs slightly west of south for 10 miles before it again approaches the shore and passes below sea-level. The lower and upper boundaries of the band are closely defined in most places, and its width, depending on the inclination of the strata, varies between 80 yards and 160 yards. Between where it disappears below the sea at both ends, it ranges from 80 feet to 160 feet above sea and outcrops on the west face of a narrow ridge surmounted by volcanic rocks. The beds dip between 45 degrees and 55 degrees to the east. The total thickness varies from 320 feet to perhaps as much as 400 feet. Though the upper and lower boundaries of the band are mostly closely defined by outcrops of the overlying and underlying strata, the iron-formation itself is largely covered by a thin mantle of drift. In the north and the south exposures are more frequent than elsewhere and indicate that the formation has developed in much the same way as the band

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4 miles to the west on the opposite side of Kipalu inlet. These two bands occur on the limbs of an arch or fold whose axis runs north and south along Kipalu inlet, and if no rupture has occurred along the central part of the fold they must curve towards one another and unite at the head of the tidal basin at the north end of the inlet. The projected course of the greater part of the western band and the extreme north end of the eastern band lie, however, in a low area without rock exposures and it is not possible to determine the precise nature of the geological structure.

In the band on the east side of the inlet, the iron-formation appears to be composed of two divisions, as in the western area. The upper division is about 70 feet thick, and is divided into three members of which the middle member is, as in the west, a grey, siliceous taconite. The lower division is about 250 feet thick and in it two ferruginous zones, 10 to 20 feet thick, occur at horizons between 170 and 215 feet above the base of the formation. These relatively iron-rich zones closely resemble the 40 to 50-foot zone found on the west shore of the inlet and in the Kasegalik Lake area. Lower down in the formation, in the lower 100 feet, there are thinner ferruginous zones and bands of the grey siliceous taconite. The whole formation is ferruginous, but only in the case of the thinner ferruginous zones in the lower 100 feet and the two thicker zones lying between 170 feet and 215 feet above the base of the formation where the strata have the general character of taconite, do the beds even approximate an iron ore. The rest of the strata are either dense rocks or lean, siliceous taconite. The different varieties of rocks appear to be grouped in zones each traceable over the whole 10-mile length of the band.

The eastern side of Kipalu inlet is a narrow peninsula chiefly of volcanic rocks sloping to the eastward. The peninsula continues southward for 30 miles beyond the southern termination of the above-mentioned 10-mile band of iron-formation. Along this 30-mile stretch the shoreline is nearly straight and the volcanics rise steeply from the water's edge except in three places where, in each case for several miles, westward projections of the land bring the iron-formation and underlying measures above sea-level. These three areas were not examined, but as seen in passing in a boat the impression was obtained that the iron-formation is very largely drift covered, except perhaps the uppermost part. The peninsula is continued southward for 12 to 15 miles by one or more low-lying islands of the volcanic rocks, but there is no reason for supposing that in this direction the iron-formation again appears above sea-level.

The volcanic rocks and the underlying iron-formation on the peninsula forming the east side of Kipalu inlet dip steeply to the east and pass under Omaralluk sound, a body of water 6 to 8 miles broad. On the east side of the sound, the volcanic rocks reappear, dipping to the west and rising in a narrow, discontinuous ridge on whose eastern slopes the underlying iron-formation is exposed. In the north this interrupted ridge of volcanic rocks is represented by a line of narrow islands paralleling Tukarak island and close to the southern part of its west coast; in the south it forms a ridge one-quarter to one-half mile wide along the western coast of Innetalling island; and farther south it forms a long, slender island and several smaller islands to the south. The extreme length of this partly submerged narrow ridge is above 40 miles and doubtless everywhere the westward-sloping volcanics are underlain by the iron-formation, but only on Innetalling island and on some of the small islands to the north, over a length of some 30 miles, does the iron-formation lie above sea-level. In the northern islands, the outcrops of the iron-formation are mainly limited to the upper part of the formation. On Innetalling island, except in the extreme north, the strata are almost wholly drift covered and were not examined. In the north part of the island, where the strata were

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examined over a length of 7 miles, the upper part of the formation is fairly well exposed, but the lower part is everywhere concealed. The strata in the north are vertical, but proceeding southward dip to the west at progressively lower angles to 45 degrees. Of the exposed part, the upper 200 feet consist of alternations of thick zones of lean, grey, siliceous taconite and thinner zones of dark dense strata. Beneath these beds and traceable for several miles in the north part is a ferruginous zone about 30 feet thick that is comparable in every way to the ferruginous zone of the Kasegalik area. A sample taken across a thickness of 24 feet of this zone was submitted to the Mines Branch for analysis and gave the following results:

Fe_2O_3	50·79
FeO	3·05
Metallic iron	37·80
SiO_2	42·12
CaO	0·50
MgO	1·44
Mn	0·35
TiO_2	0·08
S	0·04
P	0·032

A somewhat similar ferruginous zone, 15 feet thick, occurs lower in the formation, 280 feet below the top. This second horizon is exposed only in one limited area; elsewhere it and all lower beds are drift covered.

The band of iron-formation and overlying volcanics just referred to, occurs on the west limb of a long fold. The easternmost band of the iron-formation occurs on the east limb of this fold on the opposite, eastern side of a low-lying area that occupies the axial portion of the fold. This eastern band was examined only on the northern part of Innetalling island and the southern half of Tukarak island, but there is every reason to believe that it extends almost the full length of these two islands, a distance of about 60 miles, including a water-covered interval of 12 miles between the two islands. The iron-formation outcrops on the western slopes of a discontinuous ridge about half a mile wide that extends to the sea coast. The iron-formation dips eastward under the volcanic rocks at angles varying from place to place between 10 degrees and 35 degrees. On the southern part of Innetalling island only a narrow valley a few hundred yards wide separates this easternmost band of the iron-formation from the previously mentioned band of the western side of the island and in places the lower beds of the formation may extend across the valley. Along the sides of this valley outcrops are rare and, so far as known, none occurs in the bottom. Northward the valley widens and exposures are more frequent. In this direction the strata rise from the shores of a southward-extending bay and a tidal basin at its head. In places along this part of the band, the full thickness of the iron-formation of about 450 feet lies above sea-level. Owing, however, to minor folds in the strata, the iron-formation in places partly or wholly sinks below sea-level. At the north end of the island, the apparent thickness of the formation is increased by a sheet-like body of igneous rock. On Tukarak island, the iron-formation is poorly exposed and in places the drift-covering is thick. The boundaries with the overlying and underlying strata are usually closely indicated, but for stretches of a mile or more there is scarcely a single outcrop of the iron-formation.

On Innetalling island, at the north end, the iron-formation band was examined for a length of 8 miles. The lowermost and uppermost beds are well exposed in places, but the middle part of the strata is poorly exposed. The total thickness is about 450 feet; of this, the upper 200 feet corresponds with the strata of the band to the west and consists of heavy bands of grey siliceous taconite with thinner separating zones of dense dark strata. Below

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these is a thick ferruginous zone, the counterpart of that exposed in the nearby west band. Towards the base of the formation there is a thinner, less ferruginous, but otherwise similar, zone and one or more additional zones may occur higher up. The remaining strata, though in part red from the presence of comparatively abundant iron oxides, are dense and give no indication of grading into even low-grade iron ore.

On Tukarak island, the iron-formation was examined in two localities where it is locally partly exposed. One locality is about a mile south of Laddie harbour and the other 6 miles farther north. At both places the formation was found to be 370 feet thick and to present the same general succession. In the northern section a ferruginous zone commences about 25 feet below the top of the formation and extends downwards for a thickness of 40 feet. The counterpart of this zone, only partly exposed, occurs in the southern section and on the south shore of Laddie harbour. The rocks of this zone are unlike those of the ferruginous zones of the other districts. They are not taconites, but consist chiefly of iron oxides and minute, clastic grains of quartz and feldspar. Lower down in the strata of the northern section, at an horizon about 100 feet above the base, is a still lower-grade ferruginous zone of the more usual type. The two zones possibly extend continuously along at least the southern half of the band. The rest of the strata in the two areas where exposures are at all numerous, give no indication of grading into iron ore. The extent and character of the band on the north part of Innetalling island are quite unknown.

Iron-formation has been reported to occur on the large island west of Flaherty island where dark rocks of the upper part of the formation are said to rise from the water's edge. Possibly the iron-formation also occurs in the southern part of Flaherty island west of Kipalu inlet, for strata that underlie the iron-formation are known to outcrop west of the head of Kasegalik lake. The overlying volcanics outcrop east of this along the west side of Kipalu inlet and, therefore, somewhere between these two areas the intervening iron-formation must come to the surface unless it is drift covered or unless a fault occurs along the west margin of the volcanic-covered area. Since it is reported that dark rocks like the overlying volcanics form the southern part of Flaherty island the strata are probably not faulted and an undiscovered band of the iron-formation is probably developed in this extensive area.

General Considerations

Character and Distribution of the Iron-formation. The iron-formation on Belcher islands is of a type that in the Mesabi district of the Lake Superior region contains large bodies of high-grade iron ore. It has been established that these ore-bodies of the Mesabi range and those of the other Lake Superior iron ranges are secondary concentrations and did not exist when the enclosing strata of iron-formation were formed. Originally the iron-formation comprised rocks of unusual types that contained much iron in various mineral forms; but too low grade to constitute iron ore. Later in the history of these rocks, in certain localities, surface waters entered the strata, and by carrying away some constituents in solution and concentrating and redepositing others, brought about the formation of bodies of iron ore. One almost universal characteristic of this type of ore-bodies is that they extend to the surface of bedrock, although the bedrock may be covered by a considerable thickness of soil, sand, gravel, etc. This outcropping is a natural result of the ore-bodies having been caused by surface waters entering the rocks of the iron-formation and changing their composition.

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Since the iron-formation of Belcher islands is of the same general type as those of the Lake Superior region it is to be expected that if any bodies of iron ore occur, they will be local exceptional developments outcropping at the bedrock surface of the iron-formation, though perhaps concealed by drift. It is conceivable, however, that the iron-formation on Belcher islands may contain beds that from the beginning were rich in iron and that some parts of such beds were sufficiently rich to constitute iron ore-bodies. Such types of iron ore deposits occur in other regions and it is characteristic of them that the iron-rich beds vary from place to place in quality and volume. Since the ferruginous beds and any local parts of them sufficiently rich to be considered iron ore were formed when the containing strata were being laid down, the positions of the ore-bodies in the enclosing rocks is in no way connected with the manner in which the beds now may be exposed. It is a matter of chance whether the part or parts of such a bed entitled to be considered an iron ore deposit appear in the outcropping portions of the containing iron-formation or lie concealed in some part of the formation back from its outcropping edge.

These two modes of occurrence of iron ore, (1) as local, exceptional bodies or concentrations formed within and later than the iron-formation and extending downwards from the present bedrock surface, and (2) as beds formed within and contemporaneously with the iron-formation and only by chance outcropping at the present bedrock surface, are the only known ways applicable to the iron-formation of Belcher islands. This formation varies in thickness between 300 feet and 450 feet and is formed of beds of rock that differ from one another in composition and appearance, but nearly all contain much iron in various mineral forms. No beds were seen of sufficient thickness and quality to be properly called iron ore, although some zones up to 50 feet thick would, in all probability, assay better than 30 per cent metallic iron. The beds composing the formation were deposited in a body of water and were laid down on one another in horizontal layers of varying thicknesses. In some cases they extend continuously over large areas, in other cases they are more limited in extent. After some hundreds of feet of such beds had accumulated, they were covered by flows of volcanic rock and into them in some places sheet-like bodies of similar rock were injected. One such sheet appears everywhere at the top of the iron-formation just below the volcanic flows. At some period the whole group of rocks was bent into a series of long, broad folds that trend north and south and are affected by minor folds or crumples. Perhaps other rocks were laid down on the volcanic flows, but if so they have been swept away from all that part of the rocks now lying above sea-level.

The strata eventually were raised above water-level. In the course of time the volcanic rocks were eroded in places along the crests of the long, north-south trending folds, and long valleys were thus formed revealing on their sides and floors the underlying iron-formation and the strata on which the iron-formation was laid down. At the present time, the resistant volcanic rocks stand up in pairs of ridges facing one another across the axis of the long folds; along the inner slopes, or at the foot of each ridge, the iron-formation outcrops in a narrow, partly drift-covered band. Away from these long valleys, that is, in the troughs of the folds, the volcanic rocks form a continuous sheet that rests on and conceals the iron-formation.

Principles for the Prospecting of Iron Ore Deposits. If iron ore-bodies developed in the iron-formation as they have done in the Lake Superior region, they will occur along the band-like outcrops of the formation. If some parts of some of the iron-formation beds have been iron ore from the beginning then some of these richer, ore-bearing parts may chance to be exposed along the same narrow, band-like outcrops. Prospecting for iron ore-bodies should be

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systematically planned on a comparatively large scale and should consist of stripping at intervals the whole width of the bands of the iron-formation and carefully measuring and classifying the strata of the cross-sections thus exposed. By comparing the thicknesses, succession, and kinds of rock found in any one cross-section with the same features as found in the nearest cross-sections, it can be determined whether intermediate lines of stripping are required. This method of prospecting is applicable because the iron-formation is certainly an orderly succession of groups of beds, each group having a general character which it maintains for long distances. Such work should precede any search for ore-bodies by diamond drilling at localities back from the outcropping edge of the iron-formation because, in the writer's opinion, the present available information does not yet give a clue to where ore-bodies are likely to occur if they occur at all. If, however, one or two drill holes were bored in the area between the heads of Kasegalik lake and Kipalu inlet, well back from the outcropping edge of the iron-formation, they would definitely indicate whether the ferruginous zones outcropping in this general district are, as in the Lake Superior region, the products of agents of change acting at the surface or whether, as the writer believes, they were always as they now are. The iron-formation can be examined on both sides of this volcanic-covered area and the greatest thickness of volcanic rocks to be bored through is probably not above 200 feet.

Until the manner of formation of these ferruginous zones has been determined and the variation of the iron-formation along its outcrop has been worked out, it would seem unwise to commence drilling for ore beneath the cover of volcanic rocks. If the ferruginous zones are original features and somewhere along their outcrop grade into iron ore, the systematic study of suitably placed cross-sections of the strata will indicate the manner in which these zones vary and the directions along which they grow richer or poorer in their iron content and thus give some clue to the position of areas in which iron ore-bodies may occur. Drilling operations planned according to such information would yield reasonably definite results and prove the presence or absence of commercial ore-bodies. If, on the other hand, the ferruginous zones represent conditions such as led to the formation of ore-bodies in the Lake Superior iron ranges, it is equally true that the outcropping edges of the iron-formation should be examined, for according to both theory and experience the enriched deposits should outcrop there. Long stretches of the formation, that are wholly or largely drift covered, should be tested, for if ore-bodies exist they should be less resistant to weathering than the other rocks and would tend to occur in recessed areas which naturally are likely to be drift covered. In places this covering must be as much as 50 feet thick, but in most parts it probably averages less than 10 feet.

Possibilities of Secondary Ore-concentration. Unless all competent authorities are at fault, the only manner in which secondary ore-bodies could grow in these rocks would be through the action of surface waters. This action could take place only if there was an adequate, long-continued supply of such waters, if the rocks were permeable, and if the general structures were such that the underground movement of the waters was active and localized so as to abstract certain impurities and concentrate the iron oxides. It is by no means evident that these necessary conditions now prevail on Belcher islands, or that they ever did prevail, except possibly at some period so remote that any ore-bodies then formed have since been destroyed.

At present the iron-formation outcrops in narrow bands but little wider than the thickness of the iron-formation—a few hundred yards at most. In every case the outcrops are on the sides or at the foot of ridges into which the

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strata dip and are overlain by volcanic rocks which form the upper part of the slopes and the tops of the ridges. The amount of surface water now available to produce any changes in the iron-formation is limited to that which falls on the outcrop or drains from the surmounting steep face of the overlying volcanics. This supply is trivial, and since the Glacial period it has produced practically no change. Not only is the supply of surface water very slight, but the rock structures are not favourable to a vigorous underground water movement. The overlying volcanics with their slate partings form an almost impervious capping that prevents the entry or exit of water and must give rise to a condition of stagnation so far as regards any water that may have entered the iron-formation by way of its narrow outcrop.

The present situation is unfavourable to the development of ore-bodies through the concentrating action of surface waters and it is probable that similar conditions prevailed for a long period in the past while the present land forms were developing. The stages through which the land forms passed are exemplified on Innetalling island where a valley has formed along the crest of one of the long folds in the strata. In the south this valley is only between one-quarter and half a mile in width. It is bounded by the steep faces of two parallel ridges whose tops are composed of the volcanic rocks. On the opposite slopes of the valley, the iron-formation outcrops from beneath the volcanic rocks. Northward on the island, the valley widens to several miles, but the iron-formation still outcrops as two narrow bands, one on each side of the valley at the foot of, or along the steep sides of the slopes of the bounding ridges of volcanic rocks. This single valley illustrates the various stages in the growth of all the other valleys or depressions along the sides of which the iron-formation at any stage outcropped. At very early dates in some localities the iron-formation may have outcropped so as to favour the development of ore-bodies by surface waters, but that stage has long since passed, and present conditions have so long prevailed that any ore-bodies that might have been formed in the earliest stages of development of the land forms would have been destroyed. As regards the formation of ore-bodies through the action of surface waters, three general types of structures exist on Belcher islands. The most common structure is exemplified along the eastern side of Kipalu inlet (Figure 3), where the iron-formation outcrops along the sides and foot of a steep ridge. The beds dip into the ridge at angles generally above 30 degrees and pass beneath a cover of volcanic rocks. In a distance of one mile or less down the dip the covering rocks and the underlying iron-formation pass below the sea. In a few places where the iron-formation outcrops near the top of the ridge, the cover may not be very thick, but in most places at least 100 feet of volcanic rocks, in places twice this amount, must overlie the iron-formation. In such circumstances it is difficult to conceive of any active circulation of water within the iron-formation.

A second general type of structure is developed on Innetalling island and so far as known only there. The iron-formation outcrops on the two sides of a long narrow valley. The beds slope in opposite directions away from the centre of the valley, the strata exposed being on the two sides of a fold and very close to its axis. In the southern part of the island, the general land-level sinks, and it may be that in some places the iron-formation forms the rock floor of the valley and thus is preserved on the very crown of the fold. In such a position, if anywhere, the surface waters should be capable of producing an ore-body, for along the arch of the fold the strata are likely to be fractured and permeable to water, and the long, narrow valley would afford a relatively large water supply. This valley, so far as known, is floored with drift. At its north end the rock floor cannot be much above sea-level and may be

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considerably below it. At the south end it lies below sea-level and it may be that throughout the entire length of the valley the iron-formation has been largely or wholly removed. If so the special opportunity for ore formation does not exist, since the conditions along the valley sides are only a repetition of the general case exemplified along the east side of Kipalu inlet.

The third and only remaining type of structure is that prevailing between Kipalu inlet and Kasegalik lake and not known to be developed elsewhere. In this district the strata have a basin-like structure, the reverse of that referred to as yielding the second type. On the west side of Kipalu inlet near its head, the exposed iron-formation dips gently to the west beneath a ridge of volcanic rocks, and reappears several miles farther west along the margin of Kasegalik lake where the beds slope to the east. The structure is not symmetrical. Northward from a valley that extends west from Kipalu inlet to a bay on Kasegalik lake, the strata form a shallow basin which widens northward and is tilted to the northeast; southward the basin is tilted southwesterly. Such a structure in conjunction with other conditions would be favourable to active underground water circulation and the development of ore-bodies. In this district, a zone rich in iron oxides and 40 to 50 feet thick, occurs at a constant horizon in the iron-formation, about 120 feet below the summit. This zone outcrops on both sides of the basin-shaped area and its existence might be taken as satisfactory evidence that surface waters influenced by the favourable general rock structure had favoured a partial concentration of the iron contents of the strata and that somewhere along the outcropping edges of the iron-formation, or perhaps down along this zone beneath the cover of volcanic rocks, bodies of high-grade iron ore may occur.

Several features, however, indicate that the iron-rich zone is an original feature of the strata. In the first place, this ferruginous zone is not exceptional. Essentially similar zones occur without definite relation to structure wherever the strata are well exposed. Wherever this rock type was observed below a certain marked level in the iron-formation, it was found to be comparatively rich in iron oxides. Secondly, there are above the level of the ferruginous zone usually one or more thick layers of rock essentially similar to that of the ferruginous zones, but always relatively barren of iron oxides. This constantly recurring contrast suggests again that the rocks do not owe their main features to changes produced by circulating waters originating at the surface.

Thirdly, the top of the iron-formation is everywhere largely composed of iron carbonate, and these rocks are relatively easily altered and, of all the strata of the iron-formation, show the greatest amount of weathering. At the surface they have a brownish coloured, decomposed, limonitic (iron oxide plus water) outer shell in place half an inch thick, whereas the other rocks are quite fresh. These iron carbonate rocks would be much altered if surface waters had freely circulated through them for a long period of time. But except for superficial weathering they are always fresh and unaltered. It is difficult to understand in these second and third cases why a lower zone should have been altered to a relatively highly ferruginous condition, whereas overlying zones of the same character or rich in the less stable carbonate should remain unchanged. The conditions suggest that circulating surface waters had little or nothing to do with the development of the iron-rich strata.

There is yet a fourth condition which does not seem to accord with the idea that the ferruginous zones owe their high iron content to the action of surface waters circulating underground. A large part of the iron oxides is in these zones, in the form of magnetite. In places there are layers several feet thick mainly of this material. So far as known, surface waters could not form magnetite. Nor could this mineral have been produced from

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iron oxides formed by the action of surface waters, because no agencies capable of producing magnetite have acted since the strata have been accessible to surface waters. The presence of abundant magnetite is evidence, therefore, that much of the iron content of the ferruginous zones is not a product of the action of surface waters, and it would be strange if the other intimately associated iron oxides had been produced by surface waters which left the magnetite untouched. In other words, if surface waters have had any effect at all, they have merely changed some part of the magnetite to other iron oxides.

The writer is of the opinion that the zones relatively rich in iron were so from the beginning and that considering the extent of the iron-formation and how little of it has been examined, it is not impossible that somewhere one or more zones may grade into iron ore-bodies of commercial size and quality. If, however, these zones are secondary products, the results of the action of the surface waters, then it is evident that such activities have been widespread, and considering that for thicknesses of 50 feet the strata are of rocks that elsewhere have been replaced in part by high-grade iron ore, it is not unreasonable to suppose that somewhere high-grade ore-bodies may occur. In any case, it is certain that further prospecting should take the form of methodical examinations of cross-sections of the outcropping bands of the iron-formation, and this work—if the results obtained warrant the action—should be followed by drilling.

Summary and Conclusions

The iron-formation is known to occur in five bands, as follows, commencing with the most easterly.

(*a*) A band in the south part of Tukarak island extends probably for about 25 miles along the whole east side of this island. It reappears 12 miles to the south on the north coast of Innetalling island and extends south along the east side of this island for perhaps 18 miles. In the northern 5 miles of this stretch it is in places partly or wholly below sea-level. South of this, the formation lies below sea-level (Figure 3).

On Tukarak island, in two places the formation is 370 feet thick; on the northern part of Innetalling island it is 450 feet thick.

The strata for the most part are heavily drift covered, but are definitely known to outcrop in a band rarely more than 300 yards wide. The strata dip easterly at angles varying between 10 degrees and 30 degrees and pass beneath volcanic rocks that rise in a ridge which extends to the coast and is seldom more than a mile wide, usually considerably less.

The land area occupied by the iron-formation and by the volcanics with the iron-formation beneath them, is estimated to be 30 square miles.

(*b*) A band commences in the north on a small island close to the west shore of Tukarak island, and appears at intervals on some islands that extend in a line southward for 12 miles. It reappears on the north coast of Innetalling island and extends south along the west side of this island for perhaps 18 miles. South of this the formation lies below sea-level. On one of the small islands in the northern chain, the whole formation may for a short interval lie above sea-level; on the other small islands only the upper part of the formation anywhere rises above the sea. On the northern part of Innetalling island only the upper half is exposed; southward few outcrops occur.

The strata dip westward at varying angles and in places are vertical. They pass beneath volcanic rocks that rise in a ridge, seldom over half a mile wide, that extends to the coast.

The land area occupied by the iron-formation and by the volcanics with the iron-formation beneath them is estimated to be 10 square miles.

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(*c*) A band commences in the north on Flaherty island at the north end and on the east side of a tidal basin at the head of Kipalu inlet, extends south for 10 miles to where on the east shore of Kipalu inlet it sinks below the sea, to reappear three times for lengths of 1 to 2 miles in a further distance southward of 26 miles. South of this the formation lies below sea-level.

The strata dip to the eastward at from 30 degrees to 75 degrees. They pass beneath volcanic rocks that rise in a ridge seldom more than half a mile wide that extends to the coast.

The land area occupied by the iron-formation and by the volcanics with the iron-formation beneath them is estimated to be 18 square miles.

(*d*) A band commences in the north on Flaherty island, on the west side of Kipalu inlet near its head, and for 35 miles southward occurs at intervals along the coast in stretches varying in length from a few hundred yards up to 6 miles. In some places a comparatively small part of the higher beds rises above sea-level, but in the northernmost stretch about the upper half of the formation rises above sea-level and in some of the longer stretches the whole formation is above sea-level, though almost completely drift covered. The formation doubtless extends northward towards the end of the band on the east side of the inlet, but in this direction lies beneath drift-covered flats or the waters of a tidal basin.

The strata dip westward at low angles in the north, at high angles in the south. They pass beneath volcanic rocks that rise in a ridge which extends to the shores of Kasegalik lake and to a valley extending north from this lake to the northwest shore of Flaherty island. In the south the distance across this area in places is only half a mile. Northward it increases to as much as 4 miles, and still farther north the width may be 6 or 8 miles.

The land area occupied by the iron-formation and by the volcanics with the iron-formation beneath them is estimated to be 100 square miles.

(*e*) A band commences on the northeast coast of Flaherty island and passes southerly along the east side of Kasegalik lake until, about 5 miles south of the head of the lake, it sinks below lake-level. The length of this band is about 16 miles. Whether it reappears to the south is unknown.

The strata dip easterly at, as far as known, low angles. In the south only the upper part of the formation is exposed, the lower part lying below lake-level or being drift covered. Northward the number of exposures decrease and beyond the head of the lake, for some distance at least, outcrops are rare. This band is the western edge of the above-mentioned 100-square-mile area.

In addition to the definitely known bands, the iron-formation is reported to occur on a large island lying west of Flaherty island and probably it outcrops on the southern part of the island west or south of the valley of Kasegalik lake. In the southeast, although the iron-formation nowhere outcrops, it undoubtedly is present there beneath a cover of volcanic rocks which project above sea-level and occupy a further estimated land area of 50 square miles.

The total estimated land area occupied by the iron-formation and by the volcanics overlying the iron-formation is 198 square miles; the total outcropping area of the iron-formation is not greater than 15 square miles.

The volcanic rocks overlying the iron-formation occur in sheet-like bodies. They form in each area practically continuous exposures and doubtless it would be possible to determine the approximate thickness of volcanics in any given locality. In places they are known to be 200 feet thick; it is reasonable to suppose that the maximum thickness is not greater than 400 feet or 500 feet and that the average thickness is less than 200 feet.

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The total length of outcrop of the iron-formation, exclusive of the problematical areas in the south part of Flaherty island and on the island to the west, is estimated to be 110 miles, of which it is estimated only 10 miles all told are sufficiently well exposed to permit of unreservedly stating that iron ore beds are present or absent.

No iron ore deposits of commercial value under existing conditions were seen after traversing in all 40 miles of the various bands. Over most of this length it is certain that no iron ore-bodies occur in the upper one-quarter of the formation.

In each area examined on the several outcropping bands of iron-formation, highly ferruginous zones were found, and where the formation was fully exposed two or more such zones were always in evidence. With the exception of one horizon in the eastern band on Tukarak island, these zones everywhere have the same general characters. The positions of these zones in the iron-formation and their individual thicknesses vary from area to area, but in each area these characters are remarkably uniform.

In thickness the individual zones vary from 10 feet to 50 feet. Assays of samples representing thicknesses up to 24 feet and the examination of the material itself indicate that the zones are composed almost wholly of silica and iron oxides; the silica is largely in the form of quartz, the iron oxides in the form of magnetite and hematite, but a small proportion of the silica and iron oxides is combined as an iron silicate. Four representative samples gave the following results:

Silica	32·52	46·48	42·12	38·60
Iron oxides	62·04	50·05	53·84	54·62
Metallic iron	44·96	35·42	37·80	39·10

The individual zones consist of distinct beds, almost all alike in general characters but varying as regards their iron content. In general about 20 per cent of the volume consists of thin, discontinuous, highly siliceous, very lean layers. If by hand-picking these layers were removed, the metallic iron content could be raised to 50 per cent and more, but the silica content would still be 20 per cent or greater. The more purely siliceous layers are tightly welded to the other rocks and do not form zones that could be eliminated as one body, hence hand-picking would be a heavy charge against the ore produced.

The ferruginous zones represent groups of beds of rocks having many of the essential features of the rocks which yielded the iron ore-bodies of the Mesabi district, Minnesota. The associated strata are also ferruginous and might under some conditions yield an iron ore. The iron-formation has not been metamorphosed in such a fashion as to prevent the formation of ore-bodies in the way those of the Mesabi range originated.

The ferruginous zones approximate an iron ore and this may indicate that the processes which gave rise to ore-bodies on the Mesabi range also operated on Belcher islands. The failure to find ore-bodies on Belcher islands may be due to the heavy drift that covers the outcrops.

If ore-bodies of the Mesabi type are present, then by theory and experience they should occur outcropping at the bedrock surface of the bands of the iron-formation and not within the iron-formation wholly concealed by the cover of volcanic rocks.

It is considered to be improbable that the ferruginous character of these zones is due to causes such as operated in the Mesabi district. It seems rather that the ferruginous zones possessed their present characters when first formed or very soon thereafter. If this is so it is not impossible that

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somewhere they may grade into ore-bodies which, having formed when the rocks first developed, are not connected in origin with the present land surface and, therefore, may occur wholly concealed beneath the cover of volcanic rocks.

The above-mentioned two general modes of occurrence of iron ore deposits are the only known ones applicable in the case of the iron-formation on Belcher islands, and in either case it is not impossible that deposits of iron ore may occur.

Considering the, so far as known, only two possible ways in which iron ore deposits may occur on Belcher islands, the general conformity of the geological structures, the orderly fashion in which the strata of the iron-formation are grouped and succeed one another, and the regularity and constancy of the more ferruginous zones it is evident that prospecting should consist of methodical geological examinations of complete natural or artificially-bared cross-sections of the iron-formation made at intervals along the course of each outcropping band. Such cross-sections need be made only at wide intervals of say 1,000 yards or more, but would have to be supplemented by the examination of intermediate, partial cross-sections of particular horizons. In places, because of the thickness of the drift cover, diamond drilling instead of trenching or test-pitting might prove the most economical fashion of obtaining the desired information, but, in any case, drills should not be used to prospect for ore-bodies in localities back from the outcropping edge of the iron-formation until these edges have been systematically and fully examined. Until such an examination is made, the essential information requisite to ensure the success of any reasonably extensive drilling campaign will be lacking.

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